Scenario 5: Design & Play a guitar in your own tuning

Title:	Scenario 5: **Design & Play a guitar in your own tuning**		
Keywords:	frequency, pitch, fundamental, tension		
Short Description:	iMuSciCA Scenario about research concerning the parameters which influence the pitch on a string. Assignment: “Design & Play a guitar in your own tuning”: choose the right parameters to make each string ready to produce the correct tone.		
Lesson Plans included:	**5 Main Path: Design & Play a guitar in your own tuning** 0) Brainstorm & analysis: research: which tones can the instrument of your choice play on each string. 1) Exercise: change the pitch of the fundamental. Discover the influence of length, tension and thickness of the string on the tone. 2) Design your own virtual sting instrument and play it. **If more background needed your students can go back to following scenarios:** 2.1: **The sequence of natural tones** 2.2: **Natural Tones and Standing waves** 2.3: **How do Standing Waves Occur?**	Date:	19/07/2018

Educational objectives:	- to understand the concept of frequency - to measure frequencies with an analyser - to recognise the fact that strings and air columns have certain resonant frequencies - to discover that altering boundary conditions like length, tension, material and thickness of a string, change the frequency of the fundamental - to apply these insights in designing a simple instrument - to investigate the influence of a parameter, while holding other parameters fixed. - to recognize and note an inversely proportional relation - to discover a square root relation (with help)	Estimated duration:	4-6 h
Authors:	Renaat Frans, Erica Andreotti	Age Group:	Secondary (approx. 14-18)
Contributors:	Marjan Van de Moer, Mieke Schuermans, Jeroen Vanesser, Jeroen Op den Kelder, P. Stergiopoulos E.Chaniotakis, Tim Maes, Reinout Vaes, Tom Jeunen	Language:	English
Status:		Difficulty Level:	average

Dissemination level:		Special Needs Adressed:	

Make your own string Instrument - detail

Time	Phases	Field	Description	Activity	Remarks
	Engage	**E**	Exercise: make your own instrument.	The **aim** of this scenario is to **create a virtual string instrument**. Choose one of these instruments: violin, viola, cello, contrabass, bass guitar.	We start from an engineering question.
	Engage /Imagine	A	Brainstorm & analyse: Look up on which frequency each string vibrates.	Play an instrument of your choice: violin, viola, cello, contrabass, bass guitar or watch a video. Video of guitar player: https://www.youtube.com/watch?v=jOuMQk2oqpA&feature=youtu.be (We are going to rewatch this video later, so don't close it.) How many strings does your instrument contain? Look up on which frequency each string vibrates (full length). Write down the frequency (from high to low) ***Acoustic guitar:*** number of the string | frequency (Hz) | name of the note	If you haven't much time, you can of course provide the frequencies to your students as well. It is more important your students have time do some other investigations further down this lesson. One possibility is to aim at tuning a guitar in the so called 'DAdaad' tuning', a variation of the open D tuning: this way the instrument can be played even by a student which isn't a guitar player. Indeed the chords sound 'consonant' even by striking them without forming

					165 Hz	E (mi)
					220 Hz	A (la)
					293.2Hz	D (re)
					390.4Hz	G (sol)
					495 Hz	B (si)
					660 Hz	e^2 (mi)

chords with the fingers like real guitar players do.

Solutions: frequencies of the different instruments:

Bass guitar and contrabass:

E (mi) 82.5 Hz
A (la) 110 Hz
D_1 (re) 146.6 Hz
G_1 (sol) 195.4 Hz

Acoustic guitar:

e (mi) 165Hz
a (la) 220Hz
d^1 (re) 293.2Hz
g^1 (sol) 390.4Hz
b^1 (si) 495Hz
e^2 (mi) 660Hz

Acoustic guitar in 'DAdaad' tuning:

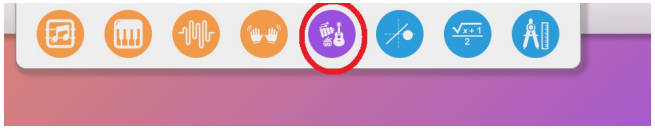
D (re) 146.6 Hz
A (la) 220 Hz
d (re) 293,2 Hz
a (la) 440 Hz
a (la) 440 Hz
d' (re) 586,4 Hz

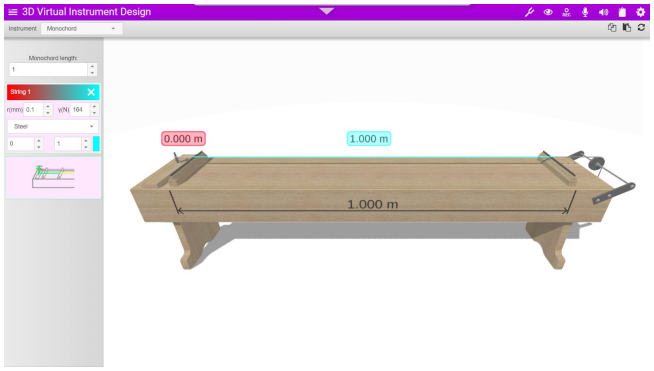
***Violin**:*

g (sol) 195.4Hz
d^1 (re) 296Hz
a^1 (la) 440Hz
e^2 (mi) 660Hz

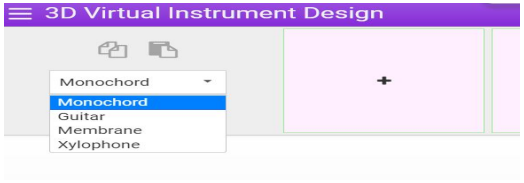
***Cello**:*

C (do) 65.1 Hz
G (sol) 97.7 Hz
d (re) 146.6Hz
a (la) 220Hz

					Viola *c (do) 130.2Hz* *g (sol) 195.4Hz* *d^1 (re) 293.2Hz* *a^1 (la) 440Hz*
	Engage	S	Learn about measuring the frequency of the fundamental tone. **definition of frequency**	In this scenario you are going to **measure frequencies** in order to find out relations between the pitch of a tone and several parameters. First look at what a frequency really is: **frequency=** the number of vibrations undergone during a unit of time (one second) by a certain vibrating system like a chord, the air or.... The unit of frequency is hertz (Hz). One hertz means one cycle or vibration per second. A frequency of a string of 440 Hz means that the string goes up and down ……. times per second.	**period** of a vibrating string = the time it takes for the string to go up and down once.
	Analyze	S	Learn about measuring the frequency of the fundamental tone using a frequency-analyser	Let's try to **measure the frequency of a sound**. To produce a sound with a fixed frequency, you can use the virtual monochord on the **3D Virtual Instrument Design Tool** (it is on the engineering tab of the iMuSciCA workbench). 	To open the 3D Virtual Instrument Design-tool click the purple music instruments icon. Look in the pedagogical guide, appendix 5 'workbench guide' for more help on how to use iMusCiCA's



Choose the monochord.



Now make a sound with the first string. Use the following parameters as indicators.

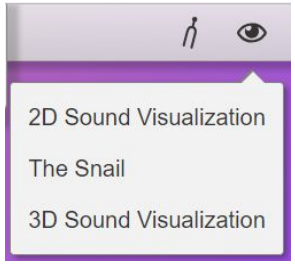
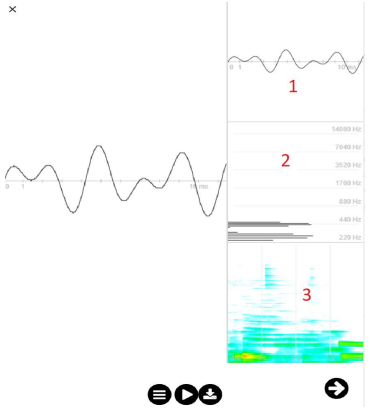
Length	1,00 m
Radius	0,1 mm
Tension (pull force)	164-187 N
Material	Steel

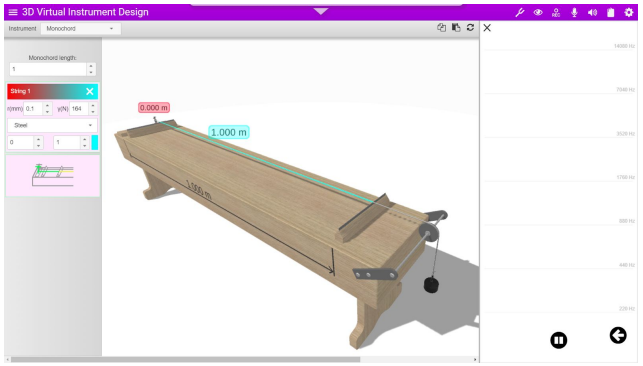
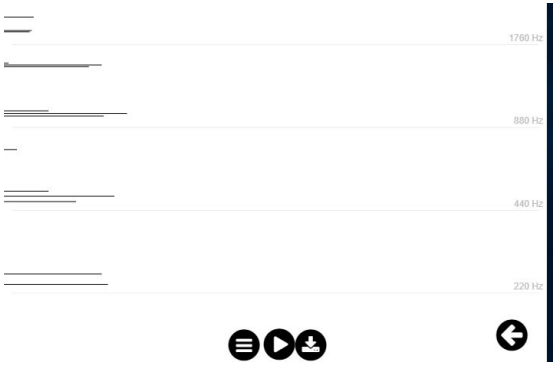
Push the button ‘try’: now adapt the tension until you hear a sound with a frequency of 440Hz.
So measure it with iMuSciCA’s 2D Sound Visualization tool.

3D Musical Instrument Design.

While measuring frequencies, the frequency of AC-voltage of the net can cause unwanted ‘noise’: peaks at the frequencies 50 Hz, 100 Hz, 150 Hz,...

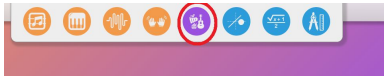
Tension is a pull force in units of Newton. Attention: in some countries the translation of ‘Tension’ can have a different meaning in physics namely force per unit of area. But this is not what is meant here.

				 It's a link in the 'visualisations' menu on the top right corner of the iMuSciCA workbench. The visualisations tools will start. Click then on the spectrometer: at the right side of the screen, number 2 as indicated on the screenshot below: the middle one  Now alter the parameters of radius, tension slightly to obtain a frequency of 440Hz.	

				 440 Hz is the frequency of the note A (la). Pause the measurement with the pause button. Look at the graph: Note that the vertical axis corresponds to frequency and horizontal axes to volume/intensity.  On the graph you can see several peaks: every peak corresponds to a certain frequency. The height of a peak tells something about the strength of	'Harmonics' are explained in scenario 'timbre'.

				the corresponding frequency. You just learned that a string vibrates at certain frequencies. The lowest of this row of frequencies corresponds to the first peak. We call this the frequency of the fundamental tone. **Alter the tension of the string until this fundamental frequency is 440 Hz**.  The other higher peaks you see correspond to harmonics. You can discover more on harmonics in scenario 3 on 'timbre'. What is the frequency of the fundamental tone of the string you have set in the monochord? *[The frequency corresponding to the first peak, the fundamental, should be 440 Hz.]* So the frequency of the fundamental tone of this string is 440 Hz.	

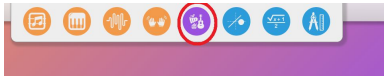
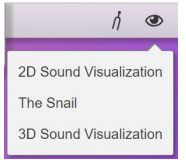
	Aangrijpen /Voorstellen	A	Explore: how can we change the pitch of the fundamental. Explore the influence of length, tension and thickness on the tone. Often, when a musical instrument is played, some parameters like length, tension etc. are altered. What happens when these parameters are changed?	We are going to find the parameters which have an influence on the pitch of a tone. Watch the video of the guitar player again: https://www.youtube.com/watch?v=jOuMQk2oqpA&feature=youtu.be) What do you notice? What does the musician change on the string when playing the guitar? [*Answ: He/She changes the length of the string.*] What changes about the tone when the musician changes the length of the string? *[Answ: The pitch (frequency) of the tone changes]* ***Conclusion:*** When you alter the length of a string, the frequency of the fundamental tone changes too. Are there other parameters which may have an influence on the fundamental tone? *[Answ.: tension, material, thickness. (There is no wrong answer here since the students have not investigated it yet)]*	More information about fundamental and overtone can be found in scenario 'Timbre'. When the fundamental is changed, overtones will change as well.

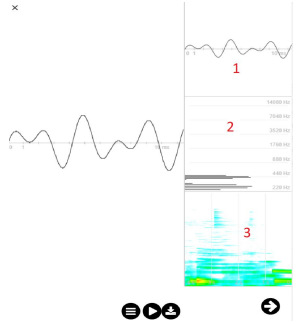
				Let's find out..  Let's investigate whether the frequency of the fundamental tone changes by changing one of these parameters.	
	Investigate/ analyse	S	**Qualitatively** investigate how the **length of a string, the tension** of the **string** and **thickness** influences the frequency of the fundamental tone.	What is the influence of the length of the string on the pitch? What is the influence of the tension of the string on the pitch? What is the influence of the material of the string on the pitch? What is the influence of the thickness of the string on the pitch? Now investigate qualitatively the influence of length, tension, material and thickness on the pitch. You can use the virtual monochord in the '3D Virtual Instrument Design Tool' or use a real monochord.	Use the virtual instruments of the iMuSciCA environment in order to investigate the influence of various parameters on the fundamental tone. You can also use a real monochord. Use the virtual monochord, on the workbench: 
	Investigate	S	**Qualitatively** investigate the influence of **length** of	Investigate how the **length of the string alters the pitch of the fundamental tone**. Use again the virtual monochord on the **3D Virtual**	At this stage you can just **listen** how the frequency changes.

			the string on the pitch of the fundamental.	**Instrument Design Tool** on the engineering tab of the iMuSciCA environment.  Change the length of the string and **listen** whether the pitch goes up or comes down. <u>Note that a higher tone means a higher frequency.</u> What happens to the frequency of the fundamental tone when the length increases? ● it increases too ● it stays the same ● it decreases *[Answ: The frequency decreases when length increases.]*	

	Investigate	S	**Qualitatively** investigate the **influence** of **tension** of the string on the pitch of the fundamental.	Investigate how the **tension** of a **string changes** the **fundamental tone**. Use the virtual monochord on the 3D Musical Instrument Design Tool on the engineering tab of the iMuSciCA environment. Change the tension of the string and listen to the produced tone. What happens with the frequency of the fundamental tone when tension increases? ● it increases too ● it stays the same ● it decreases	Use the virtual monochord on the iMuSciCA workbench. Afterwards you can verify on a real monochord. You can listen how the frequency changes. *[Answ: The frequency increases when tension increases.]*
	Investigate	S	**Qualitatively** investigate the **influence** of the **thickness** of the string on the pitch of the fundamental.	Investigate how the **thickness** of a **string changes** the **fundamental tone**. Use the virtual monochord on the 3D Musical Instrument Design Tool on the engineering tab of the iMuSciCA environment. Change the thickness of the string (by changing the radius) and listen to the produced tone. What happens with the frequency of the fundamental tone when radius increases? ● it increases too ● it stays the same ● it decreases	Use the virtual monochord on the iMuSciCA workbench *[Answ: The frequency decreases when thickness increases.]*

	Investigate	S	**Qualitatively** investigate the **influence** of the **material** of the string on the pitch of the fundamental.	Investigate how the **material** of a **string changes** the **fundamental tone**. Use the virtual monochord on the 3D Musical Instrument Design Tool on the engineering tab of the iMuSciCA environment. Change the material of the string without changing radius or tension and listen to the produced tone. What happens with the tone when the material is changed?	Use the virtual monochord on the iMuSciCA workbench *[Answ: The frequency is changed. Also the 'timbre' of the tone is changed.]*
	Communicate and Reflect	S	Communicate what you discovered.	Discuss and come to conclusions. So what did you discover about the relation between frequency of the fundamental tone and: - length? *[Frequency decreases with the length.]* - tension? *[Frequency increases with the tension.]* - thickness? *[Frequency decreases with the thickness.]* - material? *[Frequency changes when material is changed. Also timbre of the tone changes.]*	1. Length? Frequency decreases with length. 2. Tension? Frequency increases with tension. 3. Density? Frequency decreases with the thickness. 4. Material? Frequency only changes a little with material.

			You can skip the following or a part of it, if you have no time to find out the exact relations.	In the following part we are going to find out the exact relation between these parameters and the frequency of the fundamental tone.	We recommend to do at least the **quantitative investigation** of the relation between **frequency and length**, which can be done even with young students of 12-13 y.o. The other investigations (influence of tension and radius) are more advanced.
	Investigate	S	Investigate **quantitatively** how the **length of** a **string** influences the pitch of the fundamental tone.	First we try to find the **mathematical relations** between the length of the string and the frequency of the fundamental tone. Use a real monochord or the monochord in the 3D Virtual Instrument Design Tool. Measure frequency againg with the spectrometer in iMuSciCA's 2D Sound Visualization tool. You can measure the frequency by using iMuSciCA analyser on the iMuSciCA workbench: click on the	You can do the quantitative measurement on a real monochord as well as on the virtual 3D Musical Instrument Design Tool (in the engineering tab) of the workbench.   Frequency measurements can be done with the spectrometer

				spectrometer at the right of the screen:  Measure the length of the string. Make the string vibrate and measure the frequency. Remember to measure the fundamental frequency (and not the harmonics). Do the same for different lengths. Which parameters do you keep constant if you investigate the influence of the length? 1. length 2. radius 3. tension 4. material *[Answ.: radius, tension, material]*	(number 2 indicated below):  Now alter the parameters of radius, tension slightly to **Results:** When the length of a string doubles, the frequency of the tone halves. Length and frequency are inversely proportional. f ~ 1/L

First try on your own. If you have problems, you can follow the suggestions below.

Hint: measure the frequency of the string on full length L_1, on half length $L_1/2$, $L_1/3$, etc. Fill in the following table. Fill at least in until f_n/f_1 where you divide every new frequency through the first one. You can leave the last column open unless your teachers wants you to fill it in as well.

[Below in red an example of a measurement of a guitar string]

n		L_n (m)	f_n (Hz)	f_n/f_1	$L_n \cdot f_n$
1	L_1				
2	$L_1/2$				
3	$L_1/3$				
4	$L_1/4$				
5	$L_1/5$				

[Solutions of measurements done with guitar strings of nickel plated steel]

n		L_n (m)	f_n (Hz)	f_n/f_1	$L_n \cdot f_n$
1	L_1	*0,656*	*160*	*1,00*	*105*

Normally students will discover the relation already when they fill in f_n/f_1 when they divide every new frequency through the first one and see that the proportion will become larger in entire proportions while you are dividing the length of the string through the same integer.
Of course if you want to, you can let your students fill in the last column as well.

The mathematical relation between frequency and length is, according to Mersenne:

$$f = \frac{1}{2L}\sqrt{\frac{F}{\mu}}$$

2	$L_1/2$	*0,328*	*330*	*2,06*	*108*
3	$L_1/3$	*0,219*	*490*	*3,06*	*107*
4	$L_1/4$	*0,164*	*670*	*4,19*	*110*
5	$L_1/5$	*0,131*	*810*	*5,06*	*106*

Try to find the mathematical relation between length and frequency.
Fill in what happens with the frequency:

$L_1/2 \Rightarrow f$ ..... *[Answ: f*2]*

$L_1/3 \Rightarrow f$ ..... *[Answ: f*3]*

$L_1/4 \Rightarrow f$ ..... *[Answ: f*4]*

$L_1/5 \Rightarrow f$ ..... *[Answ: f*4]*

This relation is called an **inversely proportional** relation between L and f, written as $f \sim \frac{1}{L}$.
Notice in the last column that the product of length and frequency is approximately constant. When the product of 2 parameters is constant, it means there is an **inversely proportional relation** between them.

Suppose you have a string of 1.0 m on which the fundamental tone is an A (f= 440 Hz). What would be the frequency of the fundamental tone if you have a string of the same material, same thickness, same tension but with *double the* length?

or see below for the derivation

$$f = \frac{1}{2\sqrt{\pi}.L.r} \cdot \sqrt{\frac{F}{\rho}}$$

L= length (m)
F = tension (N)
μ = linear mass density (mass per length) (kg/m)
ρ = mass density = mass per volume (kg/m³)

Used strings: Nickel Plated Steel

				[Answ.: f= 220 Hz] This is also the frequency of an A, but a lower one. *(an octave lower)*	
	Investigate	S	Investigate **quantitatively** how the **radius of** a **string** influences the pitch of the fundamental tone.	Now try to find the **mathematical relations** between the **radius** of a string **and** the **frequency** of the fundamental tone. Which parameters do you keep constant if you investigate the influence of the radius? 1. length 2. radius 3. tension 4. material *[Answ. length, tension, material]* You can use a real monochord: then you have to replace the strings by thicker and thinner ones. Of course you use iMuSciCA's virtual monochord as well. You can measure the frequency again by using the iMuSciCA Visual tools spectrometer.	Notification: you find below the derivation of the formula which gives the relation between radius and frequency (Law of Mersenne) starting from the previous formula: $f = \frac{1}{2L}\sqrt{\frac{F.L}{\rho.V}}$ $f = \frac{1}{2L}\sqrt{\frac{F.L}{\rho.L.\pi.r^2}}$ $f = \frac{1}{2\sqrt{\pi}.L.r}.\sqrt{\frac{F}{\rho}}$ L= length (m) μ = linear mass density (mass per length) (kg/m) F = tension (N) r= radius (m) ρ = mass density = mass per volume (kg/m³)



Change the radius of the string. Make the string vibrate and measure the frequency. Do the same for different radii.

Hint: measure the frequency of the string on radius r_1, on double radius $2r_1$, $3r_1$, etc. Fill in the following table.
Fill at least in until f_n/f_1 where you divide every new frequency through the first one. You can leave the last column open unless your teachers wants you to fill it in as well.

n	r_n	r_n (m)	f_n (Hz)	f_n/f_1	$r_n \cdot f_n$ (m/s)
1	r_1				
2	$2r_1$				
3	$3r_1$				

Normally students will discover the relation already when they fill in f_n/f_1 . Of course if you want to, you can let your students fill in the last column as well.

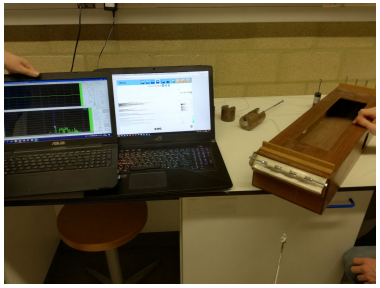
<table>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>
<table>
<tr><td>4</td><td>$4r_1$</td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>$5r_1$</td><td></td><td></td><td></td><td></td></tr>
</table>

What is your conclusion about the relation between radius of a string and frequency of the fundamental?

[Answ.: again we see an inversely proportional relation.]

Write down the relation.
[Answ.: $f \sim \frac{1}{r}$]
</td>
<td>Note that a real string is not always solid metal, but entwined.</td>
</tr>
<tr>
<td></td>
<td>Investigate</td>
<td>S</td>
<td>Investigate quantitatively how the tension of a string influences the pitch of the fundamental tone.</td>
<td>Now try to find the mathematical relations between the tension of a string and the frequency of the fundamental tone.

Which parameters do you keep constant if you investigate the influence of the tension?
1. length
2. radius
3. tension
4. material
[Answ. length, radius, material]

Use a real monochord: below is an example of such an investigation.</td>
<td>You can measure frequency with Sound Visualizer number 1 on the iMuSciCA workbench (or with VA):

Measuring frequency of a real monochord.</td>
</tr>
</table>

Or use the monochord on the 3D Virtual Instrument Design Tool on the engineering tab.
You can measure the frequency by using iMuSciCA 2D sound visualization on the iMuSciCA workbench: click on the spectrometer at the right of the screen:



Measure the tension of the string. Make the string vibrate and measure the frequency. Do the same for different tensions.

n		F (N)	f (Hz)	$\sqrt{F}$ ($\sqrt{N}$)		$f/\sqrt{F}$
1	F_1	50			f_1	

Suggestion: tension is a force (=pulling force). In order to change the tension on a real strings you can hang different masses at one extreme of the string. Use a balance to measure the mass.
The tension F is equal to the gravitational force: F= mg.
Start with m =1kg.

n		F (N)	f (Hz)		f_n/f_1
1	F_1	*9,81*	*120*	f_1	*1,00*
2 1	$2F_1$	*19,6*	*169*	f_2	*1,41*
3	$3F_1$	*29,4*	*200*	f_3	*1,67*
4	$4F_1$	*39,4*	*230*	f_4	*1,91*
5	$5F_1$	*49,1*	*250*	f_5	*2,08*

The above measurements are taken with strings of Nickel Plated Steel.

2	$2F_1$				f_2						
3	$3F_1$				f_3						
4	$4F_1$				f_4						
5	$5F_1$				f_5						

Try to find the mathematical relation between tension and frequency.
Fill in what happens with the frequency:

$F_1 * 4 \Rightarrow f * .....$ *[Answ: f_1*2]*

Can you predict

$F_1 * 9 \Rightarrow f * .....$ *[Answ: f_1*3]*

$F_1 * 16 \Rightarrow f * .....$ *[Answ: f_1*4]*

Can you see the relation between the numbers you filled in and the numbers on the left side?

[Answ.:
$\sqrt{4} = 2$
$\sqrt{9} = 3$
$\sqrt{16} = 4$ *]*

Can you find the relation between $\sqrt{F}$ and f? This is not easy…

$F * 4 \Rightarrow \sqrt{F} * 2 \Rightarrow f * .....$ *[Answ: f*2]*

$F * 9 \Rightarrow \sqrt{F} * 3 \Rightarrow f * .....$ *[Answ: f*3]*

$F * 16 \Rightarrow \sqrt{F} * 4 \Rightarrow f * .....$ *[Answ: f*4]*

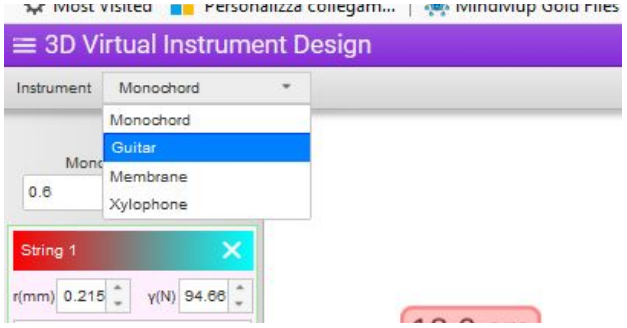
				What is your conclusion about the relation between the square root of tension of a string and the frequency of the fundamental tone? *[Answ.: we see a proportional relation between square root of tension of a string and frequency of the fundamental tone.]* Note the relation. *[Answ.:* $f \sim \sqrt{F}$ *]*	
	Communicate/ Reflect	S	What did you discover? Discuss and come to conclusions.	What did you discover about the relation between frequency of the fundamental tone and: - length? *[Frequency is inversely proportional to length.]* - tension? *[Frequency is proportional to the square root of tension.]* - thickness? *[Frequency is inversely proportional to thickness.]* We can combine these relations as followed: $f = constant.\frac{\sqrt{F}}{L.r}$	f= $\frac{1}{2\sqrt{\pi}.L.r}.\sqrt{\frac{F}{\rho}}$
	Analyse	S/A	*If you have skipped one or all the quantitative investigations, you can pick up the scenario from here.* Which constraints can you choose to make your string instrument? Length?	**Now you can start to make your own string instrument.** We are going to find out which constraints you can choose freely: ● Can you freely choose the **length** of the strings? Think about the look of your instrument. Also	*[Answ: No. The total length of the strings is fixed. The musician changes length temporarily by pressing the string with a left finger but the*

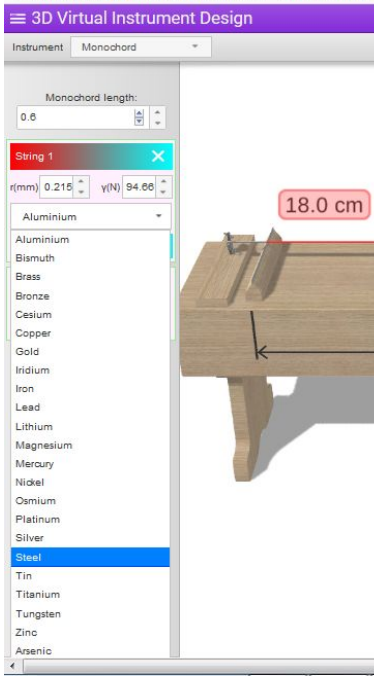
<table>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>consider that a musician must be able to play the instrument you made like he is used to.

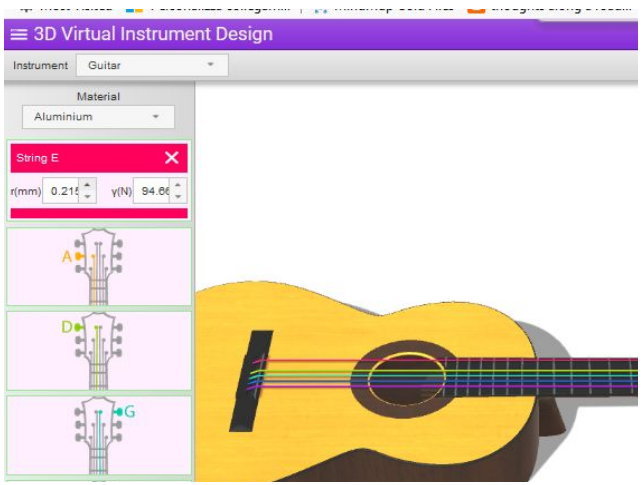
Remark that a musician temporary alters the length of the string by pressing a left finger on it.
So you can look up how long the strings of your instrument must be.
L=.....
[answ.:
<table>
<tr><th>instrument</th><th>length of string</th></tr>
<tr><td>Monochord</td><td>There are many types of monochords, but for example you can take one with string length of about 70 cm</td></tr>
<tr><td>electric guitar</td><td>around 50-65 cm depending on the type</td></tr>
<tr><td>bass guitar</td><td>70-90 cm depending on the type</td></tr>
</table>
</td>
<td>basic length of a string (also of the instrument itself) is fixed. It is determined by tradition. (Remark: for every kind of instrument there exist smaller versions for kids or smaller people.)]</td>
</tr>
<tr>
<td></td>
<td>Analyse</td>
<td>S/A</td>
<td>Which constraints can you choose to make your string instrument? Material?</td>
<td>• Can you freely choose the material of the strings?</td>
<td>[Answ: In principle you can, though there might be some tradition in materials used. You can experiment with different</td>
</tr>
</table>

				The material has also an effect on the frequency. But there are still other parameters to choose to make sure each string has its right frequency. (In this exercise we use solid strings. In reality strings of an electric guitar can also be plated (ex: steel plated with nickel.)	*materials on the virtual instrument since this influences also the timbre of the sound: warm, bright, sharp,....]*
	Analyse	S/A	Which constraints can you choose to make your string instrument? Thickness?	• Can you freely choose the thickness of each string? Note that a lower tone corresponds to a lower frequency. So the lower the fundamental tone, the *thicker / thinner* the string must be. *[Answ.: The lower the fundamental tone, the thicker the string.]*	*[Answ.: Partly. The radius too has an influence on the sound of the tone. A musician can determine the sound by choosing material and thickness of each string. Since the radius of a string has an influence on frequency of the fundamental, you can not freely choose the thickness of a string. The choice is limited because the only parameter left to choose, is tension. Tension must be chosen in an interval.]*
	Analyse	S/A	Which constraints can you choose to make your string instrument? Tension?	Are there other parameters you can choose freely? • Can you freely choose the tension of the strings, when all the other parameters are fixed? Remember that every string needs to have the right frequency.	*[Answ: No you cannot choose the tension freely once the material and thickness are chosen. Of course the player will adapt the tension slightly to make sure the string has the*

				For a certain material and thickness the ideal tension has a minimum and a maximum. The string must not be stretched too much, but on the other hand hard enough to be able to produce a good sound. So it is not intended to freely choose the tension of the strings. Tension of a string can only be chosen in an interval. Can you find out why stretching too much is not ideal? *[Answ: The neck of your instrument can bend after a while or the string can break.]* Can you find out why stretching too little is not ideal? *[Answ: The equilibrium state of the string must be straight.]* Length, material, thickness and tension together determine frequency. Since tension can only be chosen freely in an interval, also the choice of thickness is limited. Note: When playing the instrument, the musician alters the length of the strings to vary music notes. When does the musician changes tension of the string? Why does he/she do that?	*right frequency due to temperature changes etc.]* *Note: [The musician changes the tension of the strings before he/she starts playing. So he/she puts each string on its right frequency. He/she 'tunes' the instrument.]* *[Sometimes a musician needs a tone, lower than the one the last string can reach. Then the musician reduces the tension of the last string until the fundamental frequency of the string corresponds to the lower tone he/she needs.]*

	Communicate	S/A	Summarise.	The needed length of the strings you looked up, the material and thickness of each string you can freely choose (between a certain range). Which parameter must be calculated to make sure each string has its right fundamental tone? *[Answ.: tension]*	
	Create	E	Create a virtual string instrument: determine the parameters.	You are now going to make your own string instrument on the 3D Virtual Instrument Design Tool. You will apply what you have learned above. You can choose among the ones present on the 3D Virtual Instrument Design Tool:  Select your string instrument and proceed as follows: 1. Fill in the **length** of the strings in the table below. 2. Fill in the right **frequency** of each string (you already looked it up and filled it in the table on the top). 3. The following thing to do is to choose the **material** and **thickness** of each string.	A suggested exercise is to tune the ***acoustic guitar in the 'DAdaad' tuning:*** *D (re) 146.6 Hz* *A (la) 220 Hz* *d (re) 293,2 Hz* *a (la) 440 Hz* *a (la) 440 Hz* *d' (re) 586,4 Hz*

				<u>Material</u>  Characteristic of the material is the mass density ρ. Look up the mass density for your chosen material and fill it in the table below. <u>Thickness</u> Choose the radius for each string and fill it in the table.	<u>Mass density used for materials used on the workbench:</u> Steel is 7700 kg/m³ Nylon 1175kg/m³ Catgut 1300 kg/m³



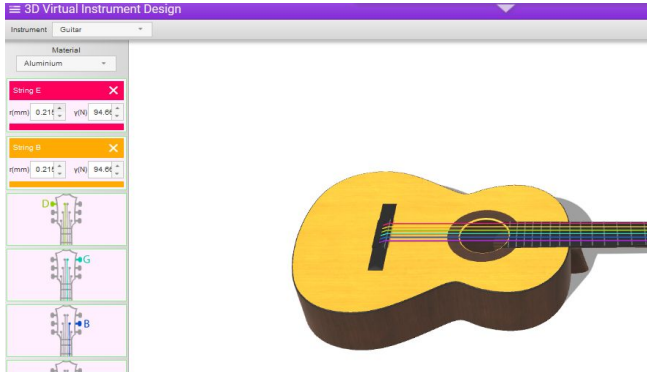
4. Write the values of frequency, density, length and radius in an excel file like following (make a copy of this file to work in):
www.steamdidactiek.be/EN_SC5_TABLE

Now for each string you can read the needed **tension** calculated in the excel file. This calculation is done according to the relations you have investigated before.

Fill the calculated tension in the table below and set all parameters on the strings of the monochord in the workbench.

Typical gauges of strings in a "Set of 10s"

	inches	mm
E (plain)	0.0100	0.2540
B (plain)	0.0130	0.3302
G (plain)	0.0170	0.4318
D (wound)	0.0260	0.6604
A (wound)	0.0360	0.9144
E (wound)	0.0460	1.1684

<table>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>
<table>
<tr><th>string</th><th>frequency (Hz)</th><th>material density</th><th>length (m)</th><th>radius (m)</th><th>tension (N)</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Create</td>
<td>E</td>
<td>Create a string instrument: set the parameters in the tool and check the frequencies.</td>
<td>Put the right parameters on the strings of your chosen instrument.


Play the strings one by one and measure the frequency.</td>
<td></td>
</tr>
</table>

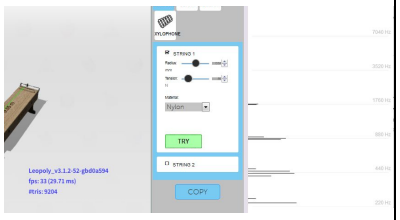
You can measure the frequency by using the iMuSciCA analyser on the iMuSciCA workbench: click on the spectrometer at the right of the screen:

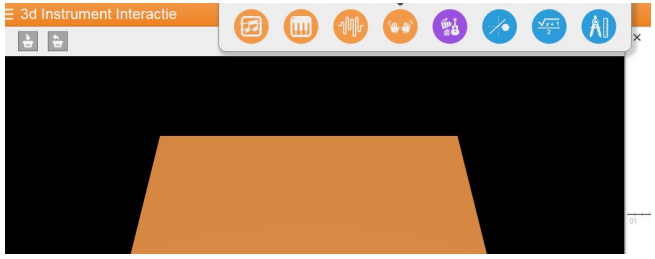


Write the measured frequency of the fundamental of each string in the table below: do they correspond to the predicted frequency?

string	note	frequency of the fundamental (Hz)
1	*e'*	
2	*b*	
3	*g*	
4	*d*	
5	*A*	
6	*E*	

Example of measurement with the Analyzer on the workbench: this is a measurement of the frequency of the A string (220 Hz):



	Creation	A	Play something on your created musical instrument.	Did you create your musical instrument? Now it is play time. **Can you play something on your created virtual instrument?** If you want to really play this instrument, try to connect a leap or kinect motion sensor to iMuSciCA and play virtually your instrument with iMuSciCA's 3D instrument interaction. 	Use for instance iMuSciCA's **3D Instrument Interaction** In this environment the student can load and play customized virtual instruments, previously designed in the 3D Musical Instrument Design activity environment. Depending on the virtual instrument, students can use their hands (Leap motion sensor) and their arms/body (Kinect sensor) to interact with the virtual musical instrument and their actions are translated into events that trigger the sound generating engine. The performance can be stored and re-played to be used in other tools (visualization, sample sequencer, analysis).

	Investigate	A	Musical exercise: identify the string which is falsely tuned.	**Let us end this scenario with some musical game.** You get a real monochord in which one string is falsely tuned. Play all the strings and try to identify which one is not tuned in the right way. Why is it not rightly tuned? What do you have to do to tune it correctly? *[Answ: you have to change the tension]* Now try to tune that string correctly.	Prepare a monochord by changing the tension of one string (e.g. by lowering the tension). To identify which string is not rightly tuned students can first just listen and then they can also measure the frequency as a verification. Also tuning the string again by increasing the tension can be done by listening and then by measuring the frequency.