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ACOUSTICS IN MUSIC EDUCATION: EMPOWERING MUSIC TEACHERS AS STEM AMBASSADORS

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ABSTRACT

Whether formally at music universities or informally in everyday conversations, it is common for acousticians to discuss acoustics-related topics with musicians or music educators. While few University programmes offer joint studies in acoustics and music, many conservatories and music universities require music students to take courses in acoustics and/or organology. At the University of Music and Performing Arts Vienna, for instance, students in both music and music education programmes can enrol in musical acoustics courses. At a time when STEM education (Science, Technology, Engineering, Mathematics – or STEAM when including the Arts) gains increasing importance, music educators have a key role to play at the intersection of music and science. They can make a difference by stimulating their pupils' curiosity about musical instruments and the science of sound, while strengthening critical thinking. To provide music educators with the necessary tools, the acoustics lecture should not only cover essential acoustic concepts, but also include strategies for conveying this knowledge. This paper proposes practical examples and discusses their applicability beyond the acoustics laboratory. This approach not only motivates future teachers while learning acoustics, but also expands their pedagogical resources for introducing STEM concepts into their music classes.

Keywords: *Music acoustics, Music education, STEM, Interdisciplinary education*

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1. INTRODUCTION

Music education and the teaching of musical instruments take place in a variety of contexts and learning and teaching situations. Whether in collective or individual lessons, in schools, institutions and private lessons, or even via online tools, the fundamental aim remains the transmission and development of musical skills and an appreciation of the art of music.

Music educators may be employed in general schools (primary or secondary) or in music schools. In general schools, the music educator teaches general musical concepts to a group of pupils. In music schools, both group lessons and individual instrumental teaching take place. The background of music educators can vary depending on how much they have specialized in one instrument. Some teachers may have studied music education at university, others may have specialized in the performance and/or pedagogy of a particular instrument, and in many cases they may be trained professional musicians who also teach their instrument. At the University of Music and Performing Arts Vienna, for example, bachelor's and master's degree programs are offered for music students who wish to teach at the secondary school level (Lehramtsstudium Musikerziehung), for music students who wish to teach an instrument (or singing) at music schools (Musikpädagogik), and for music students who wish to study instrumental performance (among other programs such as Tonmeister, composition, theatre, film...). For all these study programs, music students —many of whom might become music educators— can take courses on music acoustics at the Department of Music Acoustics – Wiener Klangstil.

In recent years, lots of studies have explored the application of technology-enhanced learning (TEL) in music [1], with examples ranging from computer- or smartphone-aided gamification tools [2] and sensoric-aided tools [3], to renderings in virtual reality [4,5]. Some studies have also addressed the challenges of preparing music educators for such digital tools [6], and examined the intersection of technology and gender in music education [7]. In parallel, many studies have highlighted the importance of music in STEM (Science, Technology, Engingeering and Mathematics), proposing methods to include music in STEM lessons [8], and proposing ways to give music a place in the 'A' of STEAM (Science, Technology, Engingeering, Arts and Mathemathics) [9, 10]. Yet only a few studies have reflected on the importance of STEM and STEAM in music teacher training [11] or have analyzed the role of acoustics in music education [12, 13].

Musicians and music educators are a very particular audience for a lecture on acoustics. They have a range of prior knowledge, including great practical knowledge of their instrument(s) and great musical skills, but also common misconceptions and beliefs about general acoustics and about the sound production in musical instruments (such as the influence of playing gestures on the produced sound). The acoustics lecture can be seen not only as a place for musicians to learn about the acoustics of their instruments, while reinforcing their critical thinking about their beliefs, but also to learn strategies for transferring acoustical concepts to their pupils. Since acoustics itself is a very interdisciplinary field, the concepts that may arise in the music lecture can be very diverse, ranging from physics and mathematical concepts to electronics, aeroacoustics, psychoacoustics, and more [9]. The current article concentrates on examples that refer to the physics of sound and showcases some exercises that the acoustics educator can use to engage with musicians and future music educators and provide them tools to become STEM ambassadors.

2. TEACHING ACOUSTICS TO (FUTURE) MUSIC EDUCATORS

In a conversation with Gordon Ramsey (Loyola University Chicago), who has recently published on the importance of acoustics and music in STEAM education [9], we shared our views on how to engage students in learning physics through acoustics and music. One of the many pieces of advice he gave me was to always think about the visual memory. "Anything you might say or have written on your slides may not last, but if you show them, it may last", were Ramsey's words. How to activate the (long-term) visual memory could therefore be seen as a motivation for the acoustics educator when preparing a lecture. Ramsey suggested preparing in-class labs and demonstrations and showing examples of the phenomena described. As an acoustics educator in a music university, I agreed and emphasized the importance of using descriptive physics. When preparing a lecture with a focus on descriptive acoustics, one can consider any topic in the field [14], while focusing on the concepts and the relationships between the physical variables, with the goal of introducing certain vocabulary, making connections between concepts, and helping students develop a deeper understanding of how physics principles apply to their instruments.

With these thoughts in mind, I have dedicated this year's lecture preparation to the question "How can I teach acoustics in a way that motivates my students (musicians and music teachers alike) to incorporate acoustics into their teaching?". The first step was to assess the current teaching situation of my students and the age of their pupils. I am currently teaching two courses on music acoustics where I meet musicians of all instruments, some specializing in performance and others in music pedagogy or education. Of the enrolled students, 15 completed a short questionnaire during the first lecture. Most of the students (11/15) are currently teaching an instrument to young pupils in private lessons, and some of them already have experience as music teachers in general secondary schools and/or teaching an instrument in music schools. The ages of their pupils were between 6 and 18 years old, with one student also teaching adults. The rest of the students (4/15) reported that they had no previous or current teaching experience.

Then I rethought the lectures to see how I could add transferable value to the demonstrations I usually show in class. So I would spend more time in class "showing how to show". For example, after we have learned what standing waves look like on a string, and they have identified nodes and anti-nodes in an in-class demonstration of a vibrating string (using a shaker and a tight elastic band), I would say to them, "I know this is some equipment that may not be available in your teaching situation, but let's try to find the similarities on a guitar". Then we would try to relate what they had just learned about standing waves to playing natural harmonics on the guitar (also known as flageolets), a technique most musicians have heard of or played themselves. If there are guitarists or violin-family players in the lecture, I encourage them to demonstrate the technique and explain what they are doing. They would claim that they touch the string lightly in a certain position to play a given harmonic (Figure 1). Then, the abstraction we do together is to relate the position of the finger with the positions of the nodes of the standing wave. They quickly understand that the finger dampens the standing waves that do not have a node in that position. During this demonstration there is often an aha moment when they see the symmetry of the standing wave, i.e., when they realize that the natural harmonics can be played both near the bridge and near the fingerboard/fretboard. I use this moment to emphasize that they could show this effect to talk about the acoustics of the vibrating string when teaching flageolets (especially for guitar and violin teachers). If they do not teach flageolets, there is usually a guitar available in every general and music school that they can use as non-guitarists to talk about the fundamental frequency and the overtones. Then we look for the positions of the nodes of the standing waves together and find out that many guitars may have fret markers or side dots that show these positions on the fretboard (Figure 1).

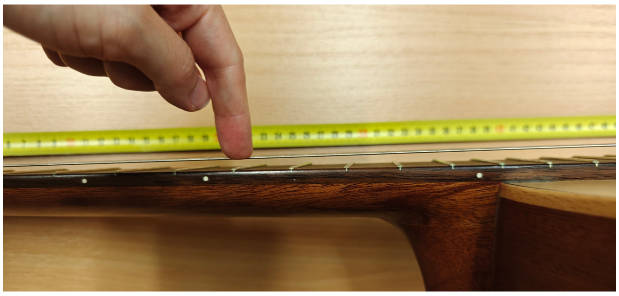

Figure 1. Classical guitar with side dots placed slightly left from the positions of 1/2, 1/3 and 1/4 on the string (from right to left). The finger is placed lightly touching the string on the fret that corresponds to 1/3 of the string.

Finding an equivalent for flageolets in wind instruments is not straightforward. The first association might be the registers: woodwind instruments can play certain notes, and they can be overblown either at an octave above or a quint-above-the-octave above the fundamental frequency that would correspond to the fingered position. Yet, according to my experience with musicians, while flageolets might be introduced very early on in the description of the string motion, standing waves in wind instruments require more careful treatment. It is common to describe the boundary conditions of wind instruments as closed or open [15]. One exercise with accessible materials (instruments) to do with musicians is to play a similar air-column length on two different instruments and discuss about the pitch of the resulting sound. From the acoustics point of view, an easy example is to compare a clarinet and a recorder. I would, first of all, ask them if they know why the recorder plays higher notes than the clarinet. They would usually reply: because the recorder is shorter. After introducing the concepts of open and closed tubes, I would ask two students to play the same length on a B-clarinet and on a soprano recorder. The recorder plays its whole length (C_5) and the clarinet plays a written D_4, sounding C_4. The first open tonehole of the clarinet is marked in red in Figure 2. The students can play the two notes and compare their interval: the flute plays one octave above the clarinet, although a similar air-column length is used. We then talk about the differences in wavelength that result in this difference in frequency. And they can finally complete the correct answer to the question of why the clarinet plays lower notes. Here, again, I would encourage teachers (clarinet teachers or anyone who might have an available clarinet at their school) to demonstrate this phenomenon to their pupils. To support the observations and shared discussions, I would show them a representation of the wavelengths of both instruments (Figure 3). If the group is interested in knowing more, one can also calculate the true length of the instrument for these frequencies according to the wavelength that is given by the frequency and the speed of sound and even introduce more advanced concepts like the end correction.

Figure 2. Comparison of the total length of a soprano recorder (sounding C_5) to the corresponding length on a clarinet (written D_4, sounding C_4). The first open tonehole on the clarinet for this demonstration is marked with an arrow.

Other examples that can be explored in the acoustics lecture while considering the transfer to the demonstration in a music lecture are collected in Table 1. These examples show some of the many useful acoustics demon-

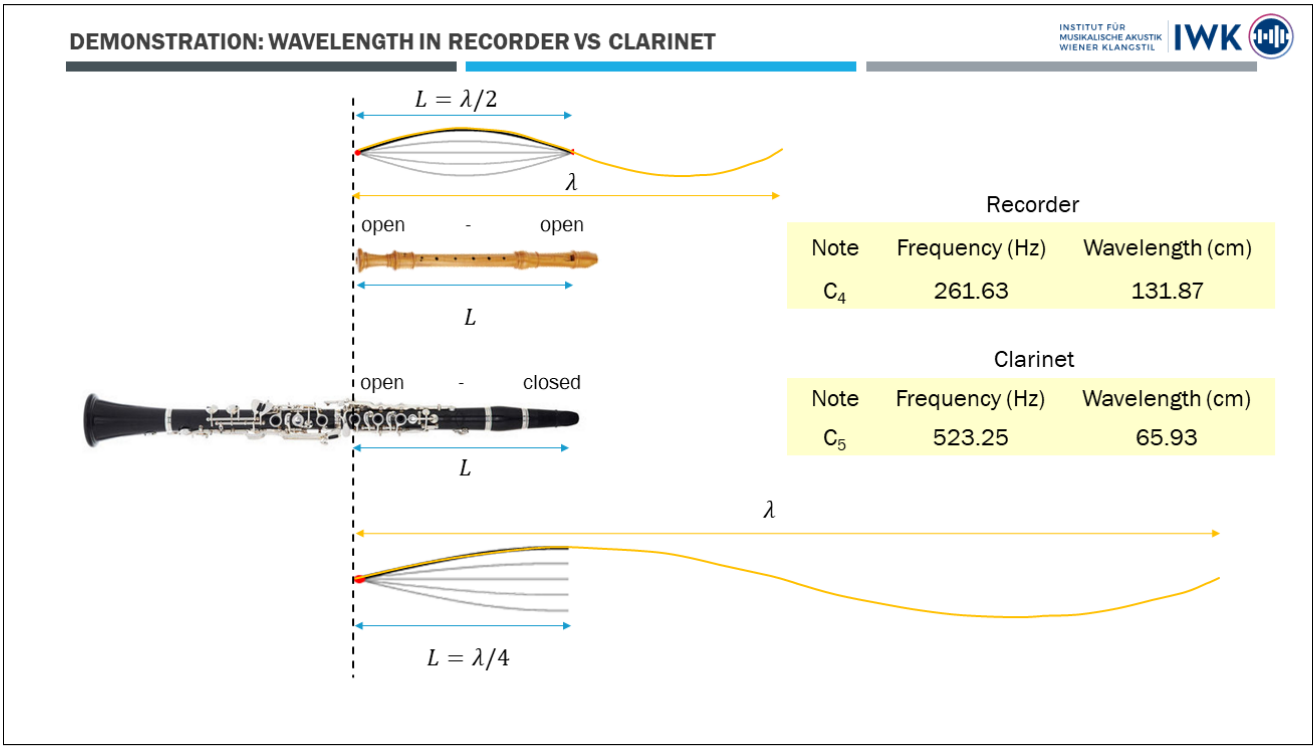

Figure 3. Comparison of the total length of a soprano recorder (sounding C_5) to the corresponding note on a clarinet (written D_4, sounding C_4)

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strations that can be explored with musicians and music teachers either in a general acoustics lecture, in a lecture on string instruments, or in a lecture on wind instruments (from top to bottom). The paper would be too long if I were to explain the exact procedure in the acoustics lecture for all six examples, as it may be similar to the two demonstrations explained above. In all cases, I would support the use of these demonstrations outside the acoustics lecture by adding sentences like “try this at home” or “try this with your pupils”, and I would ask them later if they have tried it (they claim they do!). This collection is by no means complete, but rather an inicial list of examples that the acoustics educator might consider incorporating, while presenting them as transferable demonstrations for a music lecture, and observe if the students engagement in the lecture increases, as well as their willingness to continue talking about acoustics with their pupils.

3. CONCLUSIVE REMARKS

This paper suggests that music educators have an important role to play in promoting STEM-related concepts in their music teaching through acoustics. By integrating acoustics into their teaching practices, music educators increase the interdisciplinarity of their teaching approach, not only to enhance their students’ understanding of musical instruments and the science of sound, but also to stimulate curiosity and critical thinking. In doing so, they can inspire their pupils to explore the intersection of arts and sciences, which would contribute to the broader STEAM framework. This interdisciplinary approach not only enriches music education, but also positions the music educator as a valuable contributor to science literacy and as a facilitator of knowledge and awareness of the science of sound.

The examples chosen for this paper demonstrate how practical demonstrations can be made transferable from the acoustics lecture to the music lecture. The paper pro-

Table 1. Proposed use of material that might be accessible or made available in a music school and how to introduce it both in the acoustics lecture (focusing on string and wind instruments) and the music lecture, followed by the related descriptive physics.

Accessible material	Action in the acoustics lecture	Action in the music lecture	Descriptive physics
Slinky spring	Demonstrate pressure disturbance travelling and reflecting	When talking about sound production, use a slinky to represent the particles of air	Sound waves travel when air particles get compressed and decompressed, but the air particles themselves do not move forward
Tuning fork	Press the foot piece of the tuning fork against a table or the sound box of a guitar	When talking about the role of a sound boxes, press the foot piece against a table or a guitar	The table or sound box can make the vibrations of the tuning fork audible. The table or sound box shares more surface with the surrounding air than the tuning fork.
Guitar or violin	Demonstrate natural harmonics (lightly press finger on 1/2, 1/3, 1/4 of string). Demonstrate symmetry. Make standing waves ‘visible’.	When teaching about flageolet (natural harmonics) introduce the concept of standing wave and its nodes.	The string vibration is the sum of the modes that are multiples of the fundamental frequency. These frequencies are all present in the string: the finger in the flageolet dampens the frequencies that do not have a node in this position.
Piece of paper	Blow above the paper and see how it raises; discuss Bernoulli principle. Mention plane sustain in air.	When teaching a reed woodwind instrument, introduce the Bernoulli principle to demonstrate the functioning of the reed. The paper mimics the reed.	If the particles of air gain velocity, they have less air pressure. If there are differences in pressure, objects might move (from the part where there is more pressure to the part where there is less pressure).
Clarinet and recorder	Play D in Bb-clarinet (sounding C) and C in soprano recorder, show that although similar air-column length, the clarinet plays one octave below. Discuss about their wavelengths.	Introduce the concept of open-closed and open-open tubes, by demonstrating that the clarinet can reach one octave lower than the flute.	The clarinet has a reed that creates differences in pressure at the beginning of the instrument, while the end of the instrument is open to atmospheric pressure. The flute has an air stream that moves in and out of the tube at almost atmospheric pressure.

poses to use these examples in the acoustics lecture, while including descriptive physics that links the concepts necessary to describe (some aspect of) sound production on string and wind instruments. The aim is to use accessible tools (e.g. instruments found in schools and music schools) to make acoustics engaging and relevant in different teaching contexts.

Further pedagogical development would require a thorough evaluation of the impact of the proposed action, including a follow-up with the music teachers to discuss the challenges they face in introducing acoustic concepts into their teaching practice. In addition, future research could explore other instrument families and acoustic concepts, as well as the relationship between music and other STEM disciplines, such as mathematics or electronics. For example, the mathematical principles underlying musical scales and intervals could be explored and made transferable to the music classroom [9]. Similarly, engineering concepts could be introduced by exploring the role of electronics in sound synthesis and amplification. These interdisciplinary pedagogical approaches would still need to take into account the possibilities of future music teachers in their teaching environment.

One of the main barriers to STEM education in general schools is known to be inadequate teacher preparation and a lack of interdisciplinarity [16]. This paper serves as a call to action for institutions to prioritize acoustics education in music performance and music teacher training programs, ensuring that educators are well equipped to inspire future learners at this unique intersection of STEM and arts disciplines.

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