The Physics of Music

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Physics and music have much in common. This common ground formed the basis for the Physics of Music course PHYS 490 that I taught during the Spring quarter 1994. It was an interdisciplinary course in the truest sense of the word. The students' musical experience ranged from none at all to one student who owned his own recording studio. Most of the students had little or no physics background. The only prerequisites were the science and performing arts areas of the core.

We began with a study of sound. We found that the individual notes played by musicians are actually definite frequencies and wavelengths of air vibrations. We learned that the various overtones and octaves in music are actually fixed multiples of standard fundamental frequencies of standard notes. The first two notes of the theme song from The Wizard of Oz, "Somewhere Over the Rainbow," are one octave apart. The musician hears this octave difference, while the physicist measures the frequency of the second note as exactly twice the frequency of the first note.

We experimented with simplified versions of a guitar, a clarinet and a bell. The class discovered that each of these instruments emits its own characteristic series of overtones, in addition to the actual note struck. The guitar sounds not only the note played, but notes of twice that frequency, three times that frequency, four times that frequency, and so on. It does this because the laws of physics dictate that instruments whose vibrating material is clamped firmly at both ends are able to emit all integer multiples of any note struck. The situation is different for a clarinet, because one end is open, not fixed. Its vibrating air column can emit only the basic note played, three times that note, five times that note, and so on. It is a different series of notes in addition to the basic note, so a clarinet sounds different than a guitar. The laws of physics dictate that bells emit an irregular series of frequencies in addition to the frequency of the actual note struck. This principle gives bells their "gong" sound.

Next we explored the aesthetics of musical sounds. Which notes sound pleasing together, and which do not? Which combined sounds evoke what kinds of emotional responses? We experimented with a guitar constructed for ease in making measurements to discover a principle of the physics of music noticed by Pythagoras. Guitar strings of identical construction and under identical tension produce notes that sound good, or rational, together, if their lengths are exact integer fractions of the whole length. By clamping various lengths of strings and noticing the sounds that just seemed to go together, we discovered the octave and many of the other musical intervals such as the third and the fifth.

Each student had to invent his or her own musical instrument—an instrument that had never before sounded. The inventions were based on the knowledge of the characteristic types of sounds resonated by various families of musical instruments, and on the knowledge of what musical intervals sounded good together, all of which we learned earlier. The students invented their instruments by shaping the amplitude envelopes and frequency envelopes of original pure monotones. All of these instruments were electronically programmed into the memory of a keyboard. None of them were physically

We discovered music. We measured music. We invented our own musical instruments. We computer-assembled perfect musical performances sounded by many instruments without those instruments ever being present. We learned much by discovering and by doing, and we had a lot of fun along the way.

made. We devoted one day for student presentations. A few students emulated existing instruments, and they did a good job. Most students invented instruments that were... well, ... "Far Out," to say the least. We had horror movie instruments, jet plane sounds, heavy metal instruments, jungle rhythm instruments, and other instruments I could not describe in words. At the conclusion of this portion of the course, students knew so well why instruments sound as they do that they could create any instrument to make any desired sound or evoke practically any desired emotion.

We composed MIDI music during the final weeks of the course. MIDI stands for Musical Instrument Digital Interface. My students learned how to program electronic music into a Macintosh computer. The process is similar to word processing. Instead of entering letters into the electronic memory of a computer, we use a program that enters musical notes. Just as in word processing, when we were displeased with the notes or the rhythms, we edited them to be exactly what we wanted. The final version for any instrument in the program's memory was a "perfect" solo, just as the final version of a word processing document is a "perfect" version of the document. Each student had to program at least five different instruments, all playing together forming a band. At least one of those computer instruments had to be a rhythm instrument such as a drum. Thanks to computer editing, the entire performance could be perfect. It was the logical next step, now that the students knew the basics of individual instruments. For the last days of the class, the students brought their 3 1/2 inch computer discs to class and played their compositions through the Macintosh in the classroom for the other students. I thought most of these electronic performances were astonishing. A sample of the electronic performances included, (1) a stirring rendition of a Civil War song with cannon firing and with taps played by a lone trumpet at the end, (2) a song entirely of rhythm instruments, (3) a band performance of the mathematical notions of chaos and fractals, and (4) the theme to a popular TV show performed at least as well as the TV version.

I want to acknowledge my colleagues whose assistance allowed this experience to happen. Dr. Dorothy Zinsmeister, my department Chair, had faith in me to give me the chance to teach this course. Dr. Don Davis loaned us the keyboard that all of the students used to program their invented instruments. Dr. Gary Lewis obtained the MIDI music hardware and software necessary to create MIDI music, and the music discovery equipment. Dr. Wayne Gibson allowed us to use his Department of Music and Performing Arts computer music room to assemble our final performances. Mr. Stephen Byess provided musical and MIDI expertise, and I spent many enjoyable hours discussing this course with him.

Simulations as a Strategic Training Tool for the 90s

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In a world that is rapidly changing, training in the work place has become crucial for the work force to adjust to technological changes and economic pressures. The use of simulations is an effective component in educating today's diverse work force.

A simulation is a representation of a real life situation in which elements are depicted by symbols, numbers or a physical form. It is a training device that artificially duplicates the conditions that would be encountered in an actual situation.

One of the reasons simulations are so important is that some concepts are difficult to learn from words or pictures. And in some situations it can be costly and dangerous to have inexperienced workers practice with the real systems, such as learning to fly or drive.

Simulations also can be excellent in responding to an array of different learning styles if certain guidelines are followed. For example, when preparing a simulation developers must be sure to determine if there are participants who have physical limitations that could inhibit the learning process if not addressed. The