# Board 190A: A New Educational Experience: Community College Engineering and Music Students Create User-Friendly Music Theory Application for Education and Composition

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Anita Riddle is a student of music and engineering at Salt Lake Community College. She was a commissioned officer in the U.S. Army. She also worked in the oil and gas industry. Anita Riddle is originally from Arizona. She has also lived in Germany, Alabama, Louisiana, Texas, Colorado, Virginia, and Illinois. She currently resides in Draper, Utah with her husband and two daughters.

**Miss Sierra Katherine Schmidt, Salt Lake Community College**
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Christine Schmidt is an early enrollment student at Salt Lake Community College. She expects to graduate from Corner Canyon High School in Draper, Utah in May 2023. Christine has also lived in Baton Rouge, Louisiana, Fairfax, Virginia and Spring, Texas.

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Dr. Nick M. Safai is an ASEE Fellow. He has been an ASEE officer and member for the past 36 years. He has been the six-time elected as the annual Program Chair of the ASEE International Division for approximately 15 years. Three times as the annual Program Chair for the Graduate Studies Division of ASEE. Nick has had a major role in development and expansion of the ID division. Under his term as the International Division Program Chair the international division expanded, broadened in topics, and the number of sessions increased from a few technical sessions to over eighteen sessions in the recent years. The ASEE International Division by votes, has recognized Nick's years of service through several awards over the past years. Nick has been the recipient of multiple Service awards (examples: 2013, 2010, 2006, 2004, 1996), Global Engineering Educators award (example: 2007, 2005), Best Paper award (examples: 2016, 2010, 2005, 2004, 1995) and other awards from the International Division for exceptional contribution to the international division of the American Society for Engineering Education. Examples of some Awards from other Professional Organizations: • American Society of Civil Engineers (ASCE): Engineering Educator of the Year Award 2004. • Utah Engineers Council, UEC: Engineering Educator of the Year 2005 award, in recognition of outstanding achievements in the field of engineering and for service to society. • SLC Foundation; Salt lake City, Utah: Teaching Excellence Award 2004 and 2012. * SLCC Faculkty Exemplary Service Award April 2015 and 2016. • American Society of Civil Engineers (ASCE): Chapter faculty Advisor recognition award 2002. • Computational Sciences and Education; recognition for outstanding contributions and for exemplary work in helping the division achieve its goals1998. • Engineering Division; recognition for outstanding contributions and for exemplary work in helping the division achieves its goals 1995. • Science and Humanities; recognition for outstanding contributions and for exemplary work in helping the fields achieve its May 1994. • Math & Physical Sciences; appreciation for academic expertise February 1994.

Academics: Nick Safai received his PhD degree in engineering from the Princeton University, Princeton, New Jersey in 1979. He also did a one year post-doctoral at Princeton University after receiving his degrees from Princeton University. His areas of interest, research topics, and some of the research studies have been; • Multi-Phase Flow through Porous Media • Wave propagation in Filamentary Composite Materials • Vertical and Horizontal Land Deformation in a De-saturating Porous Medium • Stress Concentration in Filamentary Composites with Broken Fibers • Aviation; Developments of New Crashworthiness Evaluation Strategy for Advanced General Aviation • Pattern Recognition of Biological Photomicrographs Using Coherent Optical Techniques Nick also received his four masters; in Aerospace Engineering, Civil Engineering, Operation Research, and Mechanical Engineering all from Princeton University during the

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years from 1973 through 1976. He received his bachelor's degree in Mechanical engineering, with minor in Mathematics from Michigan State. Nick has served and held positions in Administration (Civil, Chemical, Computer Engineering, Electrical, Environmental, Mechanical, Manufacturing, Bioengineering, Material Science), and as Faculty in the engineering department for the past twenty seven years.

Industry experience: Consulting; since 1987; Had major or partial role in: I) performing research for industry, DOE and NSF, and II) in several oil industry or government (DOE, DOD, and NSF) proposals. Performed various consulting tasks from USA for several oil companies (Jawaby Oil Service Co., WAHA Oil and Oasis Co., London, England). The responsibilities included production planning, forecasting and reservoir maintenance. This production planning and forecasting consisted of history matching and prediction based on selected drilling. The reservoir maintenance included: water/gas injection and gas lift for selected wells to optimize reservoir production plateau and prolonging well's economic life.

Terra Tek, Inc., Salt Lake City, UT, 1985-1987; Director of Reservoir Engineering; Responsible of conducting research for reservoir engineering projects, multiphase flow, well testing, in situ stress measurements, SCA, hydraulic fracturing and other assigned research programs. In addition, as a group director have been responsible for all management and administrative duties, budgeting, and marketing of the services, codes and products.

Standard oil Co. (Sohio Petroleum Company), San Francisco, California, 1983-85; Senior Reservoir Engineer; Performed various tasks related to Lisburne reservoir project; reservoir simulation (3 phase flow), budgeting, proposal review and recommendation, fund authorizations (AFE) and supporting documents, computer usage forecasting, equipment purchase/lease justification (PC, IBM-XT, Printer, etc.), selection/justification and award of contract to service companies, lease evaluation, economics, reservoir description and modeling, lift curves, pressure maintenance (gas injection analysis, micellar-flooding, and water-flooding), Special Core Analysis (SCA), PVT correlations, petrophysics and water saturation mapping.

Performed reservoir description and modeling, material balance analysis. Recovery factors for the reservoir. Administrative; coordination and organization of 2 and 6 week workplans, 1982 and 1983 annual specific objectives, monthly reports, recommendation of courses and training program for the group. Chevron Oil Company, 1979- 1983; Chevron Overseas Petroleum Inc. (COPI), San Francisco, California 1981-1983. Project Leader/Reservoir Engineer, Conducted reservoir and some production engineering work using the in-house multiphase model/simulators. Evaluation/development, budgeting and planning for international fields; Rio Zulia field – Columbia, Pennington Field – Offshore Nigeria, Valenginan, Grauliegend and Rothliegend Reservoir – Netherlands. Also represented COPI as appropriate when necessary.

Chevron Geo-Sciences Company, Houston, TX, 1979-1980 Reservoir Engineer Applications, Performed reservoir simulation studies, history matching and performance forecasting, water-flooding for additional recovery (Rangeley Field – Colorado, Windalia Field – Australia), steam-flooding performances (Kern River, Bakersfield, California), gas blowdown and injection (Eugene Island Offshore Louisiana) on domestic and foreign fields where Chevron had an interest, using Chevron's CRS3D, SIS and Steam Tube simulator programs.

Chevron Oil Field Research Co. (COFRC), La Habra 1978-1979, California. Research Engineer, Worked with Three-Phase, Three-Dimensional Black Oil Reservoir Simulator, Steam Injection Simulator, Pipeflow #2. Also performed history matching and 20-year production forecast including gas lift and desalination plants for Hanifa Reservoir, Abu Hadriya Field (ARAMCO).

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# Community College Engineering and Music Students Create User-Friendly Music Theory Application for Education and Analysis

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Abstract

Community college students invented, built, and implemented a user-friendly music theory application that enables music students to efficiently learn and analyze music in the classroom and outside the classroom quickly. It saves hours of time in applying music theory concepts to learn and analyze music. The term “music theory” is a music industry term. “Music theory” is not a scientific theory; instead, music theory represents the *structure* of music.

The key enabler was the collaboration among first- and second-year students who study engineering and music. While in the classroom, a music student contrived a clever idea for a new tool that could accelerate learning music theory and streamline the analysis of music compositions. The music student first researched available tools online. The student then reached out to the community college’s engineering department for help with the necessary creative program logic and formulas in Microsoft Excel and Google Sheets. After each music theory lecture during the semester, the music student shared the new learnings with the engineering student. The engineering student translated the music information learned into spreadsheet formulas.

After the first several weeks of work, the students presented the draft tool to the community college faculty. Faculty supported the tool’s use by students for homework, quizzes, and exams. After two semesters, faculty suggested the students receive academic credit for their research and development work. The music student and the engineering student both enrolled in the community college’s engineering special topics course each term during their remaining terms. This post-lecture research and tool development took place for four full semesters.

The first edition of the tool is used by music students with positive reviews and practical feedback. The music faculty continue to support use of this tool at the community college. The tool provided needed clarity, accelerated learning, and built confidence in at least four music theory students per term out of a class twelve who previously took excessive time with exercises and required additional faculty mentoring to succeed. The tool saves time by reducing the amount of information that must be looked up in textbooks or committed to memory.

This student-led project opened excellent research opportunities for community college students and prompted innovative teaching and studying. It inspired more students to participate in academic research and aspire to higher levels of education, including master’s and doctorates in engineering.

Background

A college level music theory curriculum typically covers many topics over four semesters. Each semester the student takes a 3-credit music theory course containing these topics:

1. music fundamentals, including music notation and chord intervals
2. harmonic progression
3. diatonic harmony
4. chromatic harmony, such as applied dominants of the V chord, modulation to other keys, modal mixture, Neapolitan sixth ($\flat II^6$), augmented sixth chords
5. Post-tonal collections and scales
6. Voice leading
7. Music phrase structure and period forms

It is the first five subjects listed above that are the subject of this study. Every note in every key for every tonal chord in those subjects is programmed into this project's spreadsheet-based tool. For each one of these music theory topics, a mathematical relationship exists between the notes. The collaboration of the music students with the engineering students enabled a time-saving tool to be created.

The music student independently began this project's journey by documenting details of music theory lessons and course textbook data into handwritten tables and notes. This academic note-taking and detailed study is normal while learning basic music theory. As expected, the student recognized that common intervals within each chord type hold regardless of musical key.

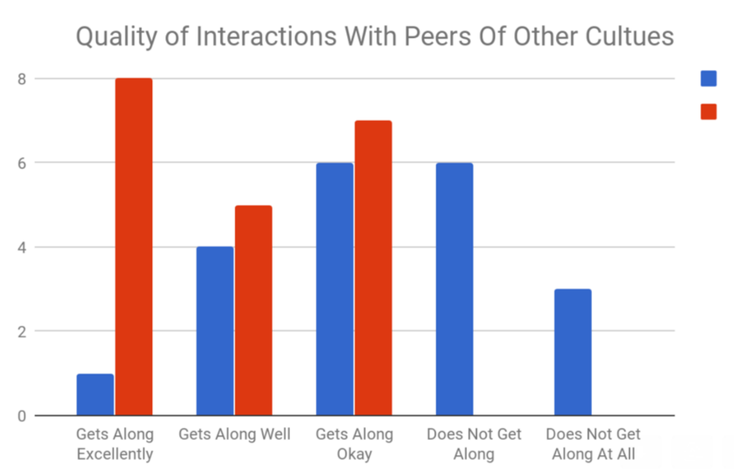
This commonality of intervals led the music student to conceive of a spreadsheet-based database with lookup functions to identify correct notes in each chord driven by the musical key. With little experience with databases and spreadsheet functions, the music student reached out to the engineering students for help.

Problems

As expected, the community college music theory student spends a lot of time studying, writing notes, listening to chords, and memorizing note intervals within chords. Many music theory students do so. The community college's target homework for a 3-credit course such as music theory, is 6 to 9 hours of homework per week. For this study, one music student with strong aural skills and perfect pitch ability, typically completed her assigned homework in the 6-hour range. Another student without prior music training or perfect pitch ability took significantly longer, up to twice as long, for some complex music analysis assignments.

These two music students explained the significant difference in their approaches to music theory mastery. The student with "perfect pitch" ability was able to immediately and correctly identify the pitches and characteristics of a played music chord just by listening to the chord. The student without "perfect pitch" required many hours of practice and textbook memorization to analyze music. This project's tool clearly accelerated the homework completion of the student without the natural "perfect pitch" ability. It is likely also very handy for any music student, regardless of his or her natural musical ability, to learn and appreciate the intricate structures of music.

Another problem emerged during the project—the communication difficulty between the researchers who came from different backgrounds and spoke different vocabularies. One had a background in music. The other in engineering. Though both are from the United States, their initial communications resembled interactions of people from different cultures. Learnings from prior research on interactions from students in different cultures were useful.[1] Figure 1 shows how this prior research showed a trend of improving quality of interactions increasing over a period of 5 months. This project's research team members remained patient and open to each other with confidence that comfort working with each other would improve with time.




Legend: Blue is September 2017 Red is January 2018

Figure 1: Quality of Interactions with Peers of Other Cultures [1]

## Existing Solutions

Several handy tools currently exist for a person to quickly find the correct notes within a chord given the key. For example, the musictheory.net website offers a series of useful free tools.[2] Additionally, ToneGym is an interactive tool to help students learn music theory concepts.  ToneGym's approach is an elegant music theory learning tool because it provides aural response for the student when using learning chord progressions, circle of fifths, and music intervals. [3] Once music theory concepts are learned, for some students it still takes either tremendous time, an extraordinary memory or strong aural skills to efficiently analyze music.

During a music theory academic course, several of these existing tools would be needed to complete homework exercises that often ask for multiple characteristics of a music passage and chords.

With musictheory.net, one tool in the series in a chord calculator provides a part of the full response of some academic music theory exercises. The user selects a musical key then clicks the starting note of the chord, then clicks the type of chord (e.g. major triad, diminished seventh), and the chord appears on the music staff. What is not shown in the resulting screen are lead sheet symbols, figured bass, Roman numerals, note resolution, proper chord ordering, and harmony type. Those characteristics of the chord are often necessary for a student to efficiently see several music theory concepts and music notations for every chord. Additionally, during music analysis, when the notes are given in a musical composition and chord identification and annotations are desired, the use of the musictheory.net "chord" or "analysis" calculator tools require more time-consuming for trial and error. The musictheory.net tools are handy for a portion of music analysis.

New Solution

This project's User-Friendly Music Theory Application helps students solidify their music theory learnings and apply music theory to analyze tonal music and several types of post-tonal music in ONE place. Music theory students benefit from this tool as it is built for a student's perspective. The tool requires one data entry type (normally the musical key). The tool is useful and fast whether the task is to identify any of these: notes in a chord, Roman Numeral, figured bass, lead sheet symbol, direction of resolution of notes in a chord, harmony type, and recommendations for tonal music chord order. Student testers found it desirable to be able to see many music theory concepts in one page instead of using multiple existing tools. The music theory concepts themselves do not change, of course--just the approach to applying music theory to analyze and even begin composition of tonal or several post-tonal types of music.

Components

No new music theory is presented in this tool.  What is new is a one-screen view of answers to many music theory student questions. The one-screen view doubles as a guide to composition. This user-friendly tool is powered mainly by a spreadsheet of notes ordered properly for tonal and many types of post-tonal music.

The User-Friendly Music Theory Application of this project contains five features:

1. Tonal Music Tool - User enters the music key. The tool delivers notes and many characteristics for 70 chords
2. Chromaticism Tool - the “Chromaticism” tab in the tool helps a student analyze the purpose of an accidental in a chord.
3. Sequences Tool - helps a student identify the most commonly seen ascending and descending musical sequences
4. Chord Progressions Tool - guidance on whether one chord should, in tonal music, follow the other.
5. Collections and Scales Tools - Octatonic collections, Hexatonic collections, Whole-Tone collections
6. Automatic Tool for 12 x 12 matrix for twelve-tone Serialism

Underlying Magic

This project’s special collaboration between music students and engineering students enabled automation via numerous tables filled with ordered notes by the music students combined with hand spreadsheet formulas entered by the engineering students.

The approach to building each tool is described here.

1. Tonal Music Tool - the tool employs spreadsheet formulas to read from a separate, large table of musical information properly and accurately. Into the large music information table, the music student entered over 1,700 data points. Each of the thirty rows has information about the thirty musical keys.

For each musical key, the music student entered data for 58 types of data, including: list of accidentals, each note in each scale degree for each chord, notes in each interval for each chord, solfege syllables, enharmonic notes, figured bass codes, lead sheet symbols, Roman numerals, indication of harmonic function, resolution direction, subsequent chords, and advice for use.

Next, the engineering student’s goal was to minimize the searching, typing and input from the user. In the user-friendly INPUT table, the user enters this data:

1. Letter of the music key (one character), e.g. A, C, G
2. Type either “flat”, “sharp”, or leave blank
3. Type either “major” or “minor”

The engineer programmed lookup tables such that on that same entry page, the user receives all the data organized into a simpler table just for that musical key entered.

Here is the form of the major lookup function that quickly retrieves the data for the user:

```
=vlookup('data lookups-no edits please'!$C$1,'data lookups-no edits please'!$A$5:$AL$35,8, false)
```

Some results are dependent on whether the musical key is major or minor, so these types of "if" statements are used also:

```
=if($Q$7="major",C15,if($Q$7="minor",C15&"m"))
```

The "major" or "minor" nature sometimes drives additional data lookups for accuracy.

```
=if(Q7="minor",vlookup('data lookups-no edits please'!$C$1,'data lookups-no edits please'!$A$5:$AC$34,28, false),vlookup('data lookups-no edits please'!$C$1,'data lookups-
no edits please'!$A$5:$AB$34,28, false)&" or "&vlookup('data lookups-no edits please'!$C$1,'data lookups-no edits please'!$A$5:$AC$34,29, false))&char(8658)&char(8664)
```

To enable the user to quickly recall that certain notes should be followed by certain other notes either up or down in tone, special characters were added to some note-retrieving formulas. Here is an example of how the down arrow of character #8664 is added to a note and how color of red alerts the user that this note is special and must be treated carefully and followed carefully by other notes:

```
=vlookup('data lookups-no edits please'!$C$1,'data lookups-no edits please'!$A$5:$V$34,22, false)&char(8664)&" to leading tone"
```

Figure 2 shows an example of what a user sees after entering the musical key in the green boxes. Each column is a chord. For each chord there is at least a BASS NOTE, third, and fifth note given. RED font alerts the user that a special resolution to a specific note is preferred in the subsequent chord. The arrow shows which way the resolution goes - up or down.

Also provided to the user is a reminder of the numbers of flats or sharps in the key and which flats or sharps those are, specifically. Figured bass notation is provided, as are lead sheet symbols and type of harmony.  The music student also added other advice learned in class and from the textbook [4]

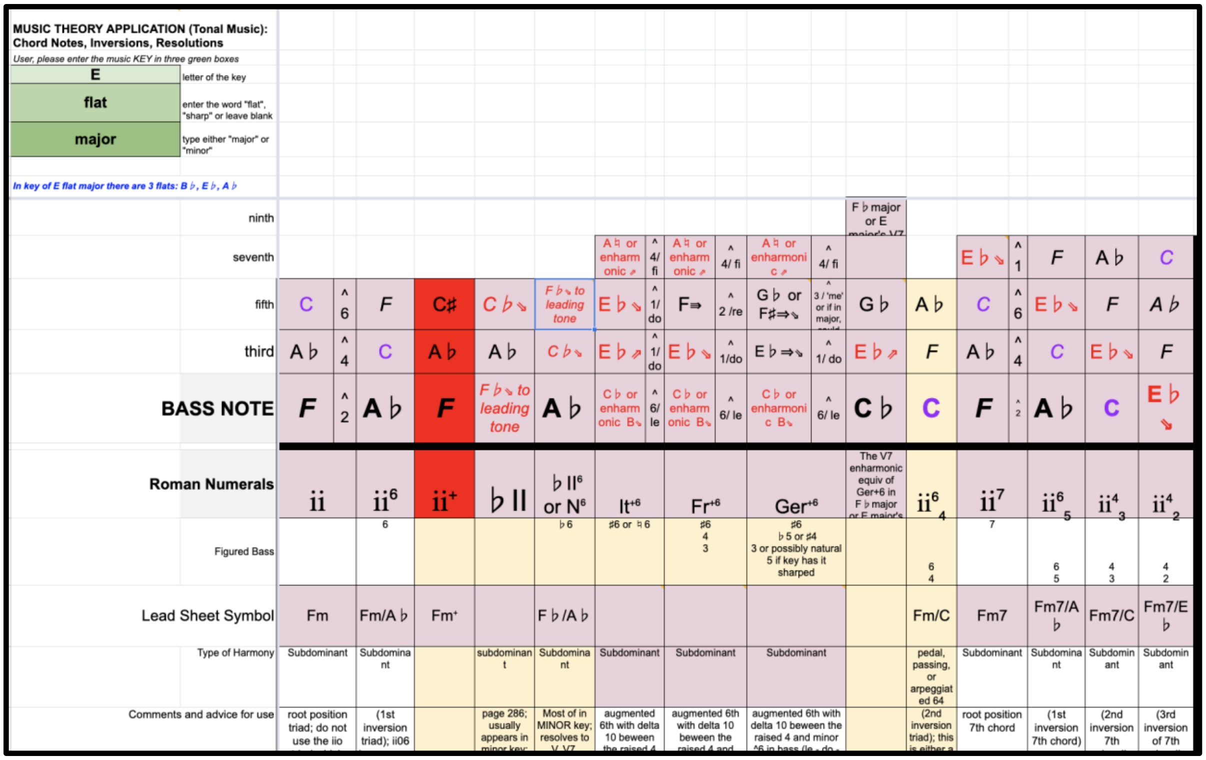



Figure 2: Excerpt from User-Friendly Music Theory Application, Tonal Music Tool, showing results for several chords in the music key of E flat Major

Feedback from music theory students using the Tonal Music Tool is that it facilitates music analysis. The tool reinforces learning since there are prompts easily visible to help the user recall important music theory concepts. Concepts taught in the classroom and available in the textbook take more time to be refreshed and recalled.

2. Chromaticism Tool: the music student developed this tool solo, as no special spreadsheet formulas were required. This is simply a table that helps a music student analyze and understand some of the possible reasons a composer added chromaticism in musical compositions.

3. Sequences Tool: This tool was also developed solo by the music student, as it did not require any formulas programming in the spreadsheet. This tool is useful for a student to recognize and identify common types of musical sequences.

4. Chord Progressions Tool: Since tonal music has many common and preferred sequences of chords, a 40 x 40 table was constructed. Each row is a chord. Each column is a chord. The intersection identifies if the chord in the column should or should not follow the chord in the row. References to textbook pages [4] are provided for a theory refresher on specific sequences of chords.

5. Collections and Scales Tools: The music student completed this part of the tool without the need of engineering student's knowledge of spreadsheet formulas. This tool consists of three separate tables, one each for Octatonic Scales, Hexatonic Scales, and Whole-Tone Scales. The music student summarized the learnings from Music Theory lectures and the textbook [4] to create these handy tables.

6.Automatic Tool for 12 x 12 matrix for twelve-tone Serialism: The user identifies a music in the style of twelve-tone serialism, then identifies the first twelve tones of the music. The user then selects those twelve tones in order from drop-down lists. The 12 x 12 matrix is automatically generated, with displays of the ordered pitch-class interval (OPCI), the inverse of the OPCI (12 minus OPCI), and importantly, the row and column indicators if P (Prime), Inversion (I), RP (Retrograde of the Prime), and RI (Retrograde of the inversion). This automatically generated 12 x 12 matrix enables the user to more quickly analyze a musician's use of different forms of twelve-tone Serialism within a piece.

The music student first created a data table showing the ordered pitch-class interval (OPCI) between every set of two notes. It is a 17 x 17 table, shown in Figure 3.

**Ordered Pitch Class Interval Calculator and Look-Up**

start note read down first then over; opci is the number in the cell

| | A♭ | A | A♯ | B♭ | B | C | C♯ | D♭ | D | D♯ | E♭ | E | F | F♯ | G♭ | G | G♯ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A♭ | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 7 | 8 | 9 | 10 | 10 | 11 | 0 |
| A | 11 | 0 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 6 | 7 | 8 | 9 | 9 | 10 | 11 |
| A♯ | 10 | 11 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 | 7 | 8 | 8 | 9 | 10 |
| B♭ | 10 | 11 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 | 7 | 8 | 8 | 9 | 10 |
| B | 9 | 10 | 11 | 11 | 0 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 7 | 8 | 9 |
| C | 8 | 9 | 10 | 10 | 11 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 6 | 7 | 8 |
| C♯ | 7 | 8 | 9 | 9 | 10 | 11 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| D♭ | 7 | 8 | 9 | 9 | 10 | 11 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| D | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 11 | 0 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 |
| D♯ | 5 | 6 | 7 | 7 | 8 | 9 | 10 | 10 | 11 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 |
| E♭ | 5 | 6 | 7 | 7 | 8 | 9 | 10 | 10 | 11 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 5 |
| E | 4 | 5 | 6 | 6 | 7 | 8 | 9 | 9 | 10 | 11 | 11 | 0 | 1 | 2 | 2 | 3 | 4 |
| F | 3 | 4 | 5 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 10 | 11 | 0 | 1 | 1 | 2 | 3 |
| F♯ | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 7 | 8 | 9 | 9 | 11 | 11 | 0 | 0 | 1 | 2 |
| G♭ | 2 | 3 | 4 | 4 | 5 | 6 | 7 | 7 | 8 | 9 | 9 | 10 | 11 | 0 | 0 | 1 | 2 |
| G | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 11 | 0 | 1 |
| G♯ | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 7 | 8 | 9 | 10 | 10 | 11 | 0 |

Figure 3. Ordered Pitch-Class Interval (OPCI) Table

The engineering student then employed the spreadsheet's INDEX and MATCH functions so the user can immediately see the ordered pitch class interval between each of the first twelve notes found in a twelve-tone serialism form of music composition. Here is an example of the formula used in the spreadsheet to find the OPCI automatically between two notes:

```
=index('opci calculator'!$B$4:$R$20,match($D$13,'opci calculator'!$A$4:$A$20,0),match($F$13,'opci calculator'!$B$3:$R$3,0))
```

The spreadsheet calculates and displays the OPCI along the top of the matrix. The inverse of the OPCI (which is 12 minus OPCI), is also calculated and inserted along a column of the automatic matrix.

With the OPCI and inverse of the OPCI calculated, the remaining notes of the 12 x 12 can be found. The music student then created a different table that shows what note must follow given a note and the OPCI shown below.

The engineering student then programmed a different formula to generate the correct note given the starting note and the OPCI.

```
=index('note semitone calculator'!$B$4:$M$25,match($D$13,'note semitone calculator'!$A$4:$A$25,0),match($C$14,'note semitone calculator'!$B$3:$M$3,0))
```

There were useful learnings for both the engineering student and the music student on the use of spreadsheet formulas. The use of VLOOKUP and HLOOKUP were previously more often used by the engineering student, but they alone were insufficient to automate the twelve-tone serialism tool. The use of the INDEX and MATCH functions provided precisely what the music student envisioned. Tool tests were conducted using exercises from the theory course workbook [5].

The music student's knowledge of twelve-tone serialism improved as more exercises were available to be completed in the time provided. The music student also needed to understand the twelve-tone serialism concepts fully to be able to accurately communicate to the engineering student what was required. The engineering student also learned about the concept of twelve-tone serialism, which was new. The music student, in turn, learned a great deal about the power of spreadsheets through use of organized databases and embedded "lookup" functions.

## Conclusion

This collaborative project enhanced learning beyond what was expected by the music students and the engineering students involved. To create this tool, the music student learned to logically organize musical data, which required additional mastery of the material to ensure accuracy. The music student also had to learn the basics of spreadsheets to communicate clearly to the engineering student what was desired.

Initially, communication issues were present, so some cross-training of concepts and vocabulary between the engineering and music disciplines was required. The engineering student had to quickly understand the basics of musical keys and chords and why they are important to musicians and students to craft a user-friendly and relevant tool. Project members researched and tried other impressive music tools and realized there may still be a gap in automated tools for music students and music analysis. After initial discussions and improvements on the original ideas, tool development progressed.

The music students dutifully and carefully entered new chord and note data into the tool's databases with each new music theory lecture. The engineering student improved personal skills with spreadsheet functions, expanding skills beyond basic VLOOKUP and HLOOKUP, which were alone insufficient to achieve the music students' goals.

The result is a useful, User-Friendly Music Theory Application. It was shared with music students in the community college's music theory class in 2022. The application was well received, however some students with very strong aural skills were able to quickly identify notes in chords for every key without a computer tool. For other less skilled music students, the User-Friendly Music Theory Application makes sense, saves time, and enhances learning because more analysis exercises can be completed with better efficiency with the tool. Confidence grows as the accuracy of the tools in the application are proven. Feedback includes suggestions to make the tool easier to use on a mobile phone and to have the laptop view of the tables less "busy".

Two students, one with "perfect pitch" ability to exactly identify notes after listening to them, and one without "perfect pitch", each recorded how much time they spent on the music theory homework during the first three semesters of music theory classes. For the three-credit class the community college homework target is 6-9 hours per week.

The chart in Figure 4 clearly illustrates the reduction in time required for one music student without "perfect pitch" to complete music theory homework with the user-friendly music theory application. Each of the two students received a grade of "A" for each of the three semesters. At least three other students per term reported reduced time to complete homework, however their data was not recorded for this study.

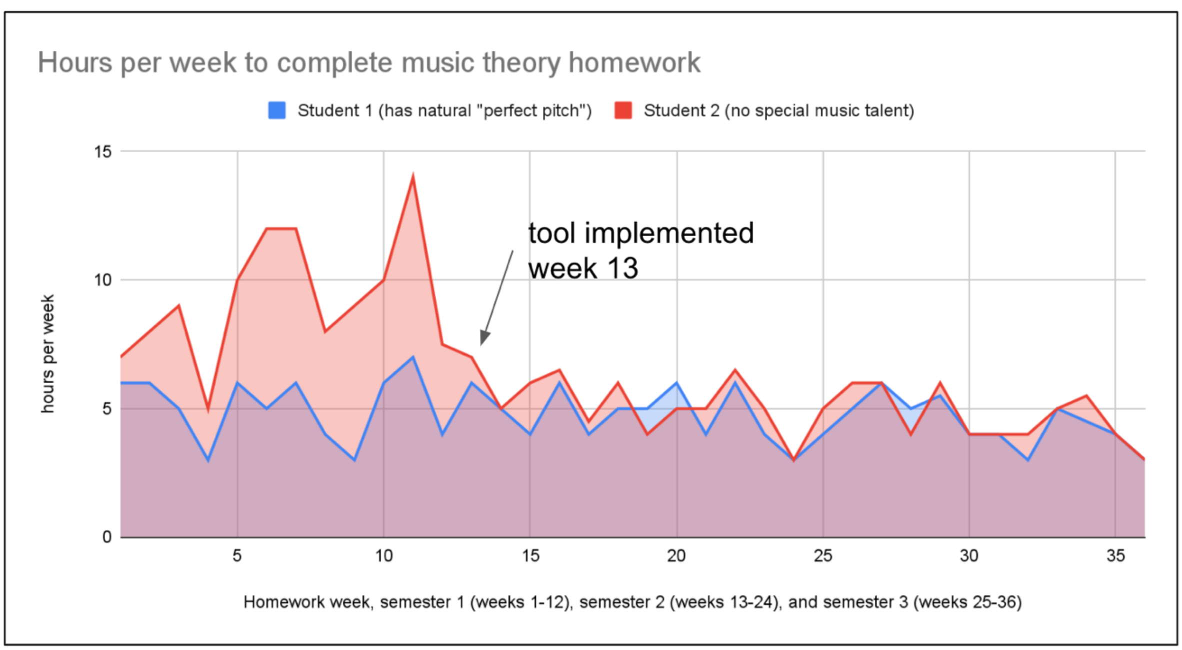



Figure 4: Hours per week to complete music theory homework

The other tools created and tested in this project are the chromaticism table, the sequences table, the chord progression table, and the collection and scales tables. Each accelerated learning, as tables included concepts and references to the lectures and textbook.

Since the testing with community college music students, the automatic twelve-tone 12x12 matrix tool was added. However, twelve-tone serialism-based music is not common, so this tool will likely not see as much use as the Tonal Music Tool and other tools. Nonetheless, analysis of twelve-tone serialism-based music compositions is accelerated.

The user-friendly music theory application was shared with research students and faculty at five different four-year universities during Spring 2023. One faculty member at a nearby four-year university requested access to the tool for her music theory class. A student at a different western four-year university requested the tool for his music composer colleague.

Next steps include testing the twelve-tone serialism with new music theory students, including at other colleges and universities, further improving the user-friendliness of the tools, and sharing more widely with composers, music teachers and other music professionals.

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[5] L. Poudie Burstein, J. N. Straus, "Concise Introduction to Tonal Harmony Workbook", 2nd Edition, Joseph N. Straus, 2020