JOURNAL OF CHEMICAL EDUCATION

Activity

pubs.acs.org/jchemeduc

Amino Acid Jazz: Amplifying Biochemistry Concepts with Content-Rich Music

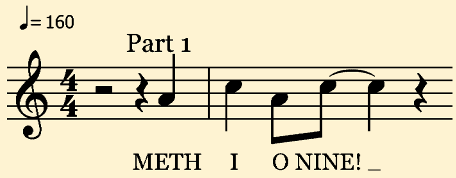
Gregory J. Crowther*,† and Katie Davis‡

†Department of Medicine, University of Washington, Seattle, Washington 98195, United States

‡The Information School, University of Washington, Seattle, Washington 98195 United States

Ⓢ *Supporting Information*

ABSTRACT: Music is not typically used in teaching high school- and college-level chemistry. This may be attributable to instructors' perceptions of educational music as being solely for memorization, their uncertainty about how to incorporate music effectively, or because of a limited number of suitable songs in which the music and words reinforce each other. To address these issues by way of a biochemistry example, we created Amino Acid Jazz, a sing-along exercise in which students synthesize a musical polypeptide from amino acid building blocks. Along the way, musical elements indicate key points about protein chemistry and structure. This exercise is an example of how the music of a song can amplify (rather than distract from) the content of the lyrics, and can thus promote knowledge acquisition that goes beyond rote memorization. Furthermore, it may be extended to incorporate students' own creative ideas. Most initial feedback from students and other teachers has been positive.



KEYWORDS: *Biochemistry, First-Year Undergraduate/General, Amino Acids, Proteins/Peptides, Analogies/Transfer, Mnemonics/Rote Learning*

■ INTRODUCTION

The addition of music to chemistry classes may engage students who would otherwise find the material dry or baffling.[1−3] Possible benefits include enhancement of recall, reduction of stress, content delivery through multiple "channels" or modalities, improved homework compliance, and opportunities to explore content creatively.[4]

In principle, these benefits could apply to students of all ages. However, classification of existing science songs and music-based lesson plans by grade level[5,6] suggests that music is used infrequently in high school and college-level courses. One potential reason for this is that educational songs are often seen only as tools for rote memorization, despite the fact that more cognitively demanding activities such as lyric analysis can also be built around them.[7] Another potential obstacle is that chemistry instructors may simply be unsure of the logistics of adding music to their curricula.

Those who do use music in chemistry education tend to agree that the songs should contain relevant, accurate content and be easy to remember.[2] The relationship between a song's music (melody, harmonies, chord progressions, instrumentation, verse-chorus-bridge structure, etc.) and its lyrics is rarely discussed, though. In many of the >7000 songs catalogued at a Web site devoted to music-based science education,[6] the music appears to serve simply as a template for the lyrics, with no obvious synergy between the two. Sometimes vocabulary words are omitted, truncated, mispronounced, or replaced with less appropriate words in order to match a melody. The educational impact of such songs would presumably be greater if the music and the lyrics were aligned more closely, especially if successful alignments were highlighted for students.

We have developed and tested Amino Acid Jazz, a sing-along exercise on protein chemistry and structure, as a practical example that addresses all of the above issues. It is straightforward to use in college-level biochemistry courses, yet it can be adapted for less advanced classes, too; it shares content with students in a manner that goes beyond rote memorization; and it demonstrates a more optimal musical encoding of the content than is typically found in educational songs. Though rich in information, it can be completed in less than 30 min. It is most effective for extending the knowledge of students who already have some knowledge of amino acids and proteins, as prior exposure may help them grasp the parallels between the music and the biochemistry content.

■ USING THIS ACTIVITY TO TEACH PROTEIN CHEMISTRY AND STRUCTURE

Amino Acids: The Building Blocks of Proteins

To arouse interest, I (G.J.C.) begin somewhat cryptically. "Let's sing a song", I say. "Repeat after me." I lead students through the alphabet song in call-and-response format, except that we only sing the 20 letters that are one-letter abbreviations for amino acids. (See Figure 1; note, though, that students do not have the handout at this point.) That is, I sing "A, C D E F G"; the students repeat "A, C D E F G"; I sing "H I K, L M N P"; the students repeat that; and so forth.

We discuss what was just sung. "What kind of strange alphabet was that?" I ask. Students will not recall exactly how many letters were included but will know that there were less

Published: October 4, 2013

dx.doi.org/10.1021/ed400006h | *J. Chem. Educ.* 2013, 90, 1479−1483

Building blocks

A	C	D	E	F	G	H	I	K	L	M	N	P	Q	R	S	T	V	W	Y
Ala	Cys	Asp	Glu	Phe	Gly	His	Ile	Lys	Leu	Met	Asn	Pro	Gln	Arg	Ser	Thr	Val	Trp	Tyr

Synthesis

Initiating Protein Synthesis
Methionine! Alanine!
Gly Glu Leu Val Ala!

Histidine Tags for Purifying Recombinant Proteins
Methionine! Alanine!
His His His His His His!
Gly Glu Leu Val Ala!

Acidic Amino Acids ("Lower the pH") and Basic Amino Acids ("Raise the pH")
Methionine! Alanine!
His His His His His His!
Lys His Arg! Asp Glu!
Gly Glu Leu Val Ala!

Phosphorylation of Serine, Threonine, and Tyrosine
Methionine! Alanine!
His His His His His His!
Lys His Arg! Asp Glu!
Leu Val Met Pro Ser-Phosphate?
Pro Phe Trp Gln Thr-Phosphate?
Ile Ala Asn Gly Tyr-Phosphate?
Gly Glu Leu Val Ala!

Disulfide Bridges Between Cysteines
Methionine! Alanine!
His His His His His His!
Trp Ser Trp Cys (-S-S-)!
Lys His Arg! Asp Glu!
Leu Val Met Pro Ser-Phosphate?
Pro Phe Trp Gln Thr-Phosphate?
Ile Ala Asn Gly Tyr-Phosphate?
Met Ser Val Cys (-S-S-)!
Gly Glu Leu Val Ala!

Figure 1. Suggested handout for Amino Acid Jazz.

than 26. "Are there some alphabets or codes that use less than 26 letters?" With encouragement, students will come to the idea that there are 20 naturally occurring amino acids and that each of these can be represented by a one-letter abbreviation.

I then distribute the handout (Figure 1) and note that amino acids also have three-letter abbreviations, which we rap (or "scat", in the jazz lexicon) in sets of three to five, again as a series of calls and responses. These three-letter abbreviations are not usually spoken aloud as abbreviations; for example, people will read "Glu" as "Glutamate" or "Glutamic Acid" rather than "glue". As the abbreviations do not have "official" pronunciations, there is leeway in how they may be spoken or sung. (For examples, consult the audio file provided as Supporting Information.)

Initiating Protein Synthesis

Having established that we can sing or rap these building blocks, I announce, "Now we will synthesize a polypeptide...-with our voices. Where should we begin?"

Perhaps a student will know that every protein begins with Methionine; if not, I volunteer this information. "And because it's so important, as the first amino acid in the whole chain," I say, "we'll sing the whole word rather than the abbreviation, like this: Me-thi-o-nine!" (See Part 1 of Figure 2 for the suggested melody.) I have the students repeat this and then add a second amino acid to the chain: "Me-thi-o-nine! Al-a-nine!" The students repeat that too.

"In a sense, a protein is nothing more than a bunch of amino acids strung together", I say. "Let's add a few more to our chain, because proteins are dozens or hundreds of amino acids long. Try this: Gly Glu Leu Val Ala!" (See Part 7 of Figure 2.) After the students sing that, we put the whole chain together: "Methionine! Alanine! Gly Glu Leu Val Ala!"

Histidine Tags for Purifying Recombinant Proteins

"Sometimes biochemists create altered forms of naturally occurring proteins", I say. "For example, six Histidines in a row might be added to one end of a protein because these consecutive Histidines will bind to a purification column, which allows this protein to be separated from other cellular components and then studied in isolation. So let's add this so-called 'Histidine tag' to our protein: His His His His His His!" (Part 2 of Figure 2.) The students repeat the His tag part (underlined in the corresponding section of the handout); then we go through the whole sequence as a call-and-response, one line of the handout at a time.

Acidic and Basic Amino Acids

"Each amino acid has a different chemical structure", I say. "For example, some of the side chains are acidic and others are basic. As you know, these affect the pH. What does an acid do to the pH of a solvent?" Some students should recall that acids lower the pH, and that bases raise the pH.

"To encapsulate this additional information", I say, "we will sing the pH-raising amino acids way up high, and the pH-lowering amino acids way down low. Like this: Lys His Arg!

Figure 2. The final polypeptide chain, as sung in call-and-response fashion. (Instructor part is in ALL CAPS.).

Asp Glu!" (Part 4 of Figure 2.) The ever-lengthening polypeptide chain is then sung all the way through, one line of the handout at a time, as before.

The remainder of the exercise proceeds in this same manner: a new concept and a new sequence of amino acids (underlined in the handout) are introduced and rehearsed, and then these are incorporated into the growing chain.

Phosphorylation of Serine, Threonine, and Tyrosine

"Another example of the amino acids' chemical diversity", I continue, "is that three of them have hydroxyl (−OH) groups that can be phosphorylated. Enzymes called protein kinases can add phosphoryl groups to these amino acids to alter the protein's structure and transmit a message of some sort."

"Three amino acids can accept a phosphoryl group: Serine, Threonine, and Tyrosine. To emphasize that these three can be phosphorylated, we'll sing, 'Phosphate?' after each one. We'll sing it with a musical question mark because the phosphorylation state of each one may change over time, depending on the conditions in the cell. Also note that these 'phosphorylatable' amino acids occur among all of the other amino acids, with no obvious pattern to their locations within the chain."

Disulfide Bridges between Cysteines

"The side chain of Cysteine ends in a sulfhydryl group, −SH", I say. "This −SH group can be linked to another −SH group from another Cysteine that appears far away in the linear amino acid sequence, but that is near the first Cysteine in three-dimensional space. This is because when these amino acid chains fold up into complex 3D shapes, different parts of the chain wind up near each other. The covalent bond that forms between two −SH groups is called a disulfide bridge because it consists of two oxidized sulfur atoms in a row. We can write this chemically as −S−S−, and we can sing it as 'SSSS−SSSS'" [hissing like a snake].

"Like the other amino acids, Cysteines appear in the sequence as a seemingly random distribution, with no obvious pattern."

"To remind ourselves that these disulfide bridges can form between Cysteines that are far apart in the amino acid sequence, we'll create a musical bridge between a Cysteine toward the beginning of the protein and a Cysteine toward the end of the protein. We will mark the Cysteines involved by hissing after each one: −S−S−."

After the Cysteine-containing sections (Parts 3 and 6 of Figure 2) are added, the polypeptide will be 41 amino acids long, which is long enough to give students a good sense of what amino acid sequences are really like. An audio file of the full polypeptide sung in call-and-response format is provided as Supporting Information.

■ SUMMARIZING SYNTHESIS

There are several ways to wrap up this exercise. A concise, straightforward summary might review the following points.

There are 20 naturally occurring amino acids in cells.
Each amino acid has a one-letter abbreviation and a three-letter abbreviation.
Each amino acid has a chemically unique side chain.
When strung together, amino acids form proteins.
The first amino acid of a protein is Methionine. After that, anything goes!
Artificial sequences of amino acids, such as 6-Histidine tags, can be inserted into proteins to simplify purification (or for other purposes).

dx.doi.org/10.1021/ed400006h | J. Chem. Educ. 2013, 90, 1479−1483

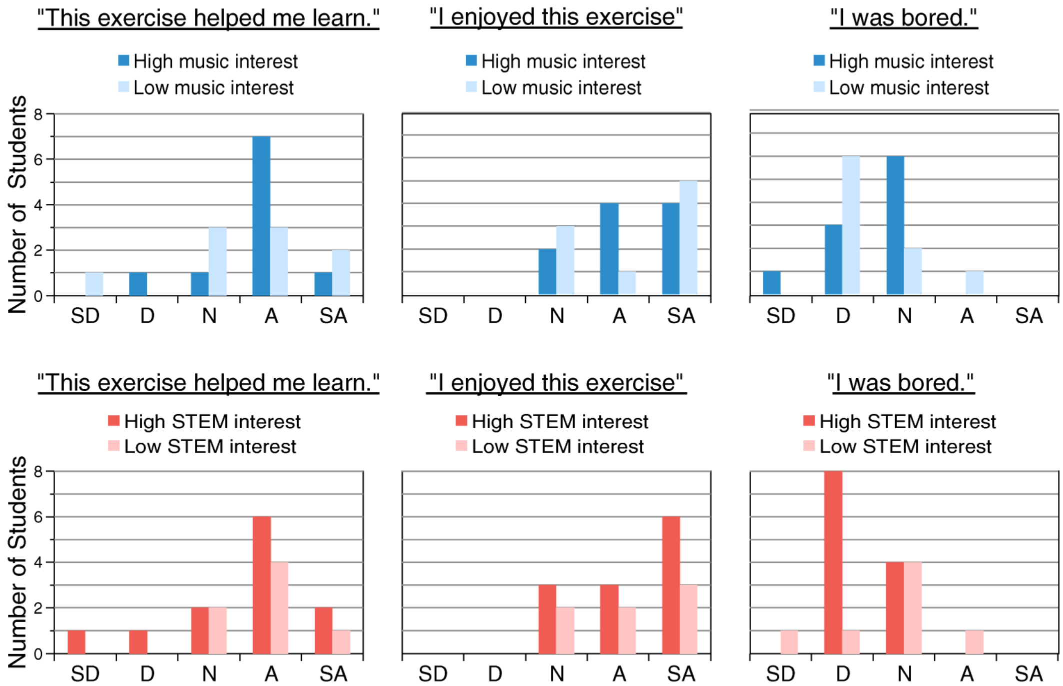


Figure 3. Students' responses to the postexercise survey statements (left to right), stratified according to interest in music (top panels) or interest in STEM (bottom panels). Response choices were "strongly disagree" (SD), "disagree" (D), "neutral" (N), "agree" (A), and "strongly agree" (SA).

Aspects of proteins' 3D structure include phosphorylation of some Serines, Threonines, and Tyrosines, and disulfide bridges between Cysteines.

One could also discuss the extent and limitations of the parallels between the music and protein synthesis. For example, as the exercise has the flavor of vocal jazz improvisation, it may be interesting to raise the question, "Is protein synthesis inside cells an 'improvisational' process?" Some students will answer "no" because cells link amino acids in the exact order specified by a gene. However, *which* protein a ribosome is making at any given moment depends on which mRNA happened to reach it at the right time, which in turn depends on the cell's current needs and an element of chance. From this perspective, a ribosome might be described as improvising in response to changing conditions.

THEME AND VARIATIONS

The exercise can be altered according to the learning goals of a class. For example, if the concept of a Histidine tag is not considered relevant, that part can be left out. The exercise can also be extended, if desired. For instance, different types of genetic mutations could be illustrated by taking a musical polypeptide and either changing a single amino acid (for a point mutation) or changing all amino acids downstream of the mutation until a premature stop is reached (for a frameshift mutation). Or pairs of students could be asked to synthesize and share their own polypeptides, either representing the amino acids as before or devising new musical "codes". This would give students a framework in which to be creative, rather than simply following the lead of the instructor.

EVALUATING THE ACTIVITY

The first iterations of this exercise were done as demonstrations for groups of high school biotechnology instructors and college science instructors. Both groups embraced the activity enthusiastically; for instance, an entomology professor exulted, "Now I finally know why proteins are His-tagged!" Some instructors suggested that the exercise could be made more visual by showing the chemical structures of the amino acids more completely and explicitly. This reasonable suggestion highlights the limitations of this or any music in covering scientific content. Music is *not* ideal for covering details such as the exact structure of each amino acid, and should supplement established instruction methods rather than replacing them. However, just as hands-on laboratory activities may solidify and deepen students' understanding of topics covered previously in a lecture, "voice-on" exercises may be similarly valuable.

Additional field-testing was done during a six-week summer "Music + STEM" course of 22 rising 11th and 12th grade students. Informed consent was obtained from 19 of the students. They came from three high schools whose proportions of economically disadvantaged students and students of color are among the highest in Seattle. All 19 students had taken high school biology; 13 had taken chemistry as well, and 17 reported having some instrumental or vocal music experience.

As part of our evaluation of the sing-along, we investigated whether its effects varied according to students' interest in either music or STEM (science, technology, engineering, and mathematics) or both. In a precourse survey, students rated their main interest as "music" ($N = 5$), "STEM" ($N = 7$), "both" ($N = 5$), or "neither" ($N = 2$). We subsequently classified students as "high music interest" (main interest listed as "music" or "both"; $N = 10$) or "low music interest" (main interest listed as "STEM" or "neither"; $N = 9$), and also as "high STEM interest" (main interest listed as "STEM" or "both"; $N = 12$) or "low STEM interest" (main interest listed as "music" or "neither"; $N = 7$).

The Amino Acid Jazz sing-along was conducted following a pair of 60-min lectures on DNA transcription and translation. Students were led through the handout (Figure 1) essentially as

dx.doi.org/10.1021/ed400006h | *J. Chem. Educ.* 2013, 90, 1479−1483

described above. A video recording of the sing-along indicated that ≥90% of students participated actively in the singing.

Could the model of the sing-along help students forge their own connections between music and science? During a subsequent class period, groups of four to five students were given 15−20 min to brainstorm about how they might use music to convey additional biochemical information. Each group was given a worksheet with two boxes to be filled in: "Additional scientific information or concept to cover" and "How we could convey this information or concept musically." The groups were successful in listing song-worthy content, such as the distinction between hydrophilic and hydrophobic side chains, and the fact that a protein whose length is X amino acids could have 20^X possible sequences. Creating musical reinforcements of this content proved challenging within the time constraints, though three of the five groups were able to generate four or more lines of song lyrics. In future work we hope to provide greater facilitation of student science songwriting, as Emdin has done.[8]

In a brief postexercise survey, students were asked to rate their level of agreement with the statements "This exercise helped me learn about amino acids and proteins"; "I enjoyed this exercise"; and "I was bored during this exercise". While the small sample size and study design preclude firm conclusions, the responses suggested a mostly favorable impression of the exercise. Responses to the first two statements did not differ greatly between high music interest and low music interest groups or between the high STEM interest and low STEM interest groups (Figure 3). There was a tendency toward less boredom (i.e., more disagreement with the statement "I was bored during this exercise") in the low music interest and high STEM interest groups. These data offer a preliminary hint that a musical intervention may be engaging even for those who do not self-identify as musically inclined, and, conversely, that music may not always increase engagement among those who are generally disinterested in STEM.

Most students did not answer an open-ended survey question inviting their suggestions for improving the exercise. The most common responses were "more singing" (3 students) and "more time" (2 students), again suggesting widespread enjoyment of the activity.

■ CONCLUSION

Beyond teaching protein structure per se, Amino Acid Jazz illustrates how songs' educational impact depends upon the interplay of the words and the music, rather than the words alone, and is not limited to rote memorization.

For imparting the lesson that a protein is made from a set of diverse components strung together in a seemingly random order, the jazz idiom of scat words fits nicely. Students can string together words more quickly and easily than they can build a physical model of a protein; in this sense, the exercise is highly efficient. Moreover, when we screech "Lys His Arg!" in a cacophonous falsetto, the sound is memorable, and the corresponding content easy to recall. In reviewing the material at a later date, students should be able to reconstruct the connection between the sounds and their meaning: "Why did we sing those three so high? Oh yeah: they raise the pH. So they must be the ones with basic side chains." In this way, the music stimulates metacognition, an important facet of learning,[9] as well as memorization.

Amino Acid Jazz is intended to be an especially vivid and clear example of successfully marrying music and chemistry-based lyrics, yet there are others. High school teacher Mark Rosengarten's song "Bromothymol Blues" uses the blues style of music to underscore the color of bromothymol blue.[10] A song from They Might Be Giants, "Solid Liquid Gas", aimed at elementary school students, uses a slow tempo for the word "solid" and faster rhythms for "liquid" and "gas" to convey the relative speeds of molecular vibration in each state.[11] And songs about neurotransmitters can be performed in styles consistent with the physiological roles of the molecules (e.g., a high-energy tempo for a verse about norepinephrine, a fight-or-flight neurotransmitter).[12] While not all content can be represented musically in a helpful way, those who use music to teach chemistry should aim for a convergence of music and lyrics when possible.

■ ASSOCIATED CONTENT

Supporting Information

Live audio recording (MP3) of the full polypeptide chain sung in call-and-response format. This material is available via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: crowther@u.washington.edu.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank Wendy Silk of UC-Davis and David Aarons, Maureen Munn, and Leny Valerio-Buford of the University of Washington for enabling pilot testing of this exercise.

■ REFERENCES

(1) Pye, C. C. *J. Chem. Educ.* **2004**, *81*, 507−508.

(2) McCammon, W. G. L., Jr. *Chemistry to Music: Discovering How Music-Based Teaching Affects Academic Achievement and Student Motivation in an 8th Grade Science Class.* Doctoral dissertation, North Carolina State University, Raleigh, NC, 2008.

(3) Last, A. M. *J. Chem. Educ.* **2009**, *86*, 1202−1204.

(4) Crowther, G. *CBE Life Sci. Educ.* **2012**, *11*, 26−30.

(5) Crowther, G. J. *Biochem. Mol. Biol. Educ.* **2012**, *40*, 19−22.

(6) Sing about Science and Math. http://singaboutscience.org/wp/lesson-plans/ (accessed Sep 2013).

(7) Governor, D.; Hall, J.; Jackson, D. *Int. J. Sci. Educ.* **2013**, *35*, 3117−3140; http://www.tandfonline.com/doi/abs/10.1080/09500693.2012.690542 (accessed Sep 2013).

(8) Emdin, C. *Urban Science Education for the Hip-Hop Generation*; Sense Publishers: Rotterdam, 2010.

(9) Hacker, D. J.; Dunlosky, J.; Graesser, A. C., Eds. *Handbook of Metacognition in Education*; Routledge: New York, 2009.

(10) Rosengarten, M. *Chemistry Classics Collection* [DVD]. 2009.

(11) They Might Be Giants. *Here Comes Science* [CD/DVD]. Disney Sound: Burbank, CA, 2009.

(12) Hermann, M.; Lilly, M. L.; Wilson, K.; Russell, N. A. *J. Nurs. Educ.* **2012**, *51*, 517−520.