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Integration of Math Jingles into Physiology Courses

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Biology, especially physiology, includes quantitative relationships that explain key concepts, yet many biology students have poor math skills or math anxiety which might hinder their learning. We propose that students who are motivated to learn but are intimidated by math may benefit from in-class activities such as singing or listening to content-rich jingles that make the relevant math more accessible. Here we describe a three-part process by which we have used feedback from 231 students in four college physiology classes to develop math-related jingles suitable for use in similar classes. In Part 1, we report three classes' overall reactions (>60% positive) to educational songs as reported in standard multiple-choice surveys, while noting the limitations of this approach. In Part 2, we mine open-ended survey comments for common themes among students' reactions. Among music-related comments, we repeatedly find three main constructive suggestions: songs should be kept very short; connections between lecture material and songs must be obvious; and songs must be heard or sung more than once to be maximally helpful. In Part 3, we present seven mathematical physiology jingles (with URLs for online access) whose development was driven partly by insights from Part 2.

Key words: content-rich songs, educational music, physiology mnemonics, musical equations.

The Next-Generation Science Standards and Vision and Change report – representing current best practices for K-12 and undergraduate education, respectively – state unequivocally that mathematical literacy is a central component of biology education (American Association for the Advancement of Science, 2011; NGSS Lead States, 2013). Thus, quantitative reasoning should be included in all high school and college biology courses, yet this is more easily said than done. Among the sciences, biology has a reputation for harboring students and faculty who dislike or fear math (Sorgo, 2010). Indeed, at the college level, performance on standardized multiple-choice math tests is lower among college biology students than in their counterparts studying computer science, physical science, and engineering (Wai et al., 2009). We and others have observed that many college biology students struggle with many aspects of simple algebraic equations: remembering them, solving them, grasping their conceptual meaning, embracing their relevance to biology, and so forth (Breckler et al., 2013; Watkins & Elby, 2013).

Numerous possible strategies for improving biology students' math skills have been noted by authors such as Madlung et al. (2011). These include incorporating more math problems into biology classes, incorporating more biology problems into math classes, creating more math-centric biology textbooks, getting biologists and mathematicians to team-teach biology, and developing new hybrid biology/math courses. These approaches could perhaps be complemented with efforts to make math more fun and engaging for the students, thus reducing barriers to learning. In the context of teaching statistics, Lesser & Pearl (2008) offer a "taxonomy of fun" – including such modalities as humor, kinesthetic activity, music, and poetry – and advice on implementing fun activities. More specifically, the use of music to enliven mathematics and statistics courses has been discussed cogently by others (Robertson & Lesser, 2013; Lesser, 2014) and is a primary theme of this special issue.

Here we explore a somewhat different use of music: to emphasize and clarify important mathematical relationships found in *biology* courses. In particular, we show how simple equations can be presented and sometimes explained in the form of song lyrics, potentially promoting both memorization and understanding. Our efforts are focused on physiology, a core component of biomedical science taken annually by hundreds of thousands of high school, undergraduate, and graduate/professional students in North America alone (Human Anatomy & Physiology Society, 2006).

Our long-term goal is to determine whether content-rich STEM songs can improve students' academic performance, as suggested by some previous reports (VanVoorhis, 2002; McCurdy et al., 2008; Smolinski, 2011; Lesser et al., 2014). However, the answer to this question may depend heavily on whether students like the songs and the pedagogy in which they are embedded. Thus, as a preliminary step toward our ultimate goal, we have used students' feedback on classroom song interventions to guide the creation of short math jingles that may be broadly useful to physiology teachers and students. The purpose of this paper, therefore, is to report on this feedback-guided song development process and the songs resulting from it; we plan to assess actual learning gains in future work.

Methods

General Methods

Courses and students studied. As part of our ongoing exploration of educational science music (Crowther, 2012a; Crowther & Davis, 2013;

Crowther et al., 2016), we collected and examined feedback on educational songs used by the lead author in teaching quarter-long (11-week) undergraduate physiology courses on three different campuses during 2014 and 2015. The courses and campuses are as follows: Biology 220 (Introductory Physiology), University of Washington-Seattle (UWS; 145 to 573 students); Biology 241-242 (Human Anatomy & Physiology for pre-nursing students), South Seattle College (SSC; 18 students) and University of Washington-Bothell (UWB; 27 students); Biology 352 (Anatomy & Physiology for biology majors), UWB (30 students). The 200-level courses (220 and 241-242) are considered introductory courses and are taken mostly by freshmen, sophomores, and juniors of various majors; the 300-level course (351) is taken predominantly by junior and senior biology majors. While detailed demographic information on the students was not obtained, the proportion of "non-traditional" (older) students is relatively low at UWS, somewhat higher at UWB, and even higher at SSC.

Different subsets of the above courses were used in the three different parts of the study described below; Table 1 shows which courses were used in which parts. In order to maximize narrative clarity, the study's parts are not presented in a strictly chronological order.

Song development. Five to nine physiology songs were incorporated into each of the above courses; 26 different songs were used in all. Songs were generally written specifically for the above courses by the lead author. The songs were intended to cover material central to many physiology courses, and to present information as well as possible within the constraints of musical rhythms and rhymes. Seven of the songs covered mathematical relationships, as discussed below.

Song implementation in the classroom. Songs were generally performed live by the instructor in the classroom *a cappella* (without instruments), though karaoke backing tracks were used occasionally. Each song was performed once. Lyrics were simultaneously provided to students via PowerPoint slides. Students were sometimes encouraged to sing along and/or make gestures illustrating the meaning of the lyrics. Lyrics and sheet music were also available to students outside of class via the instructor's website, but links to these files were not always included on the slides.

Ethical treatment of human subjects. No personally identifiable information was collected in this study. Because this study's surveys were originally created and administered primarily for purposes of course development, they were not prospectively reviewed by an Institutional Review Board (IRB). However, the subsequent decision to publish the data was approved by the Human Subjects Division of the University of Washington.

Researcher positionality. The lead author taught all of the students surveyed in this study. In presiding over the classes listed above, he made no attempt to hide his enthusiasm for science-based music, and may have given students the impression that he expected them to enjoy it as well. Thus, it is possible that the lead author's position of authority over the students influenced the students' responses even though the responses were collected anonymously. The other authors had no relationship with the lead author's students.

Table 1
Timeline of Study

	Spring 2014	Summer 2014	Winter 2015	Spring 2015	Summer 2015
Part 1: Students' overall reactions to physiology songs			Bio 241 (SSC)	Bio 241 & 352 (UWB)	
Part 2: Students' detailed reactions to physiology songs	Bio 220 (UWS)				
Part 3: Development of a suite of math -themed physiology jingles		Bio 220 (UWS)	Bio 352 (UWB)	Bio 352 (UWB)	Bio 242 (UWB)

Part 1: Students' Overall Reactions to Physiology Songs

All SSC and UWB students completed Likert-style survey questions of the following format: "To what degree did [course component] help you learn the material? (A) very helpful, (B) helpful, (C) neither helpful nor unhelpful, (D) unhelpful, (E) very unhelpful." Course components that we asked about included songs as well as (depending on the quarter) in-class discussions, in-class worksheets, kinesthetic movements, laboratory exercises, and study guides/practice tests. These surveys were completed by >90% of enrolled students. To simplify analysis, the categorical responses above were converted to numbers between 0 (very unhelpful) and 4 (very helpful).

Part 2: Students' Detailed Reactions to Physiology Songs

General UW student evaluations of teaching. UWS students completed standard anonymous end-of-quarter course evaluations administered by UW's Office of Educational Assessment. These evaluations asked students to rate many aspects of the course and the instructor on a 0-to-5 scale, and also to answer the following open-ended questions: "Was this class intellectually stimulating? Did it stretch your thinking? Why or why not? What aspects of this class contributed most to your learning? What aspects of this class detracted from your learning? What suggestions do you have for improving the class?" These optional evaluations were completed (either online or in person, depending on the quarter) by 59% to 76% of enrolled students (depending on the quarter).

To classify students' song-related comments, the following categories were created post hoc. (A) Songs were a positive aspect of the course, without specific mention of themes C, D, or E below. (B) Songs were a negative aspect of the course, without specific mention of themes C, D, or E below. (C) Songs' length and/or class time devoted to discussing them were excessive. (D) Connections between song lyrics and lectures were not always clear or strong. (E) Songs would be more beneficial if heard or sung multiple times (i.e., more than the one time each was presented in class).

Song-specific survey. After one quarter, Biology 220 students at UWS were invited to complete a survey about the six specific songs used during that quarter: “Erythropoietin,” “Fick’s Law of Diffusion,” “Meet My Threshold,” “Surface Area-to-Volume Ratio,” “The Sodium Jeer,” and “Where Is That Sound?” (“Fick’s Law of Diffusion” and “Surface Area-to-Volume Ratio” focused on mathematical relationships; the others did not.) Performance and discussion of these songs – which varied greatly in style and length – collectively filled 24 minutes of class time, spread over 17 hours of animal physiology lectures. (An additional 17 hours of plant physiology lectures did not include songs and were not covered by this survey.) Students were asked to rate each song as a very poor use of class time, poor use of class time, okay use of class time, good use of class time, or very good use of class time. To simplify the analysis, these categorical responses were converted to numbers between 0 (very poor use of class time) and 4 (very good use of class time). Students were also asked whether the maximum amount of class time that should be devoted to a content-rich song should be 0 minutes, 1-2 minutes, 3-4 minutes, 5-6 minutes, 7-10 minutes, 10-20 minutes, or more than 20 minutes. This survey was completed by only 15% of enrolled students, probably reflecting the delayed timing of the survey and the limited motivation of students to complete it at that point.

Part 3: Development of a Suite of Math-Themed Physiology Jingles

In reflecting on Part 2 of this study, the lead author decided to expand his repertoire of math-related songs beyond “Fick’s Law of Diffusion” and “Surface Area-to-Volume Ratio.” He identified additional mathematical relationships that seemed sufficiently important to merit inclusion in most physiology survey courses. He then wrote out key phrases about each relationship and tried to find rhythms and melodies that suited these phrases. For example, the central lesson of Poiseuille’s Law is that flow is proportional to vessel radius raised to the 4^{th} power. The idea arose that this relationship could be captured in the phrase “r times r times r times r,” with the repetition of the key variable providing appropriate emphasis. The song was then built around this phrase, with a verse to introduce the topic and a chorus to deliver the equation itself (Figure 1).

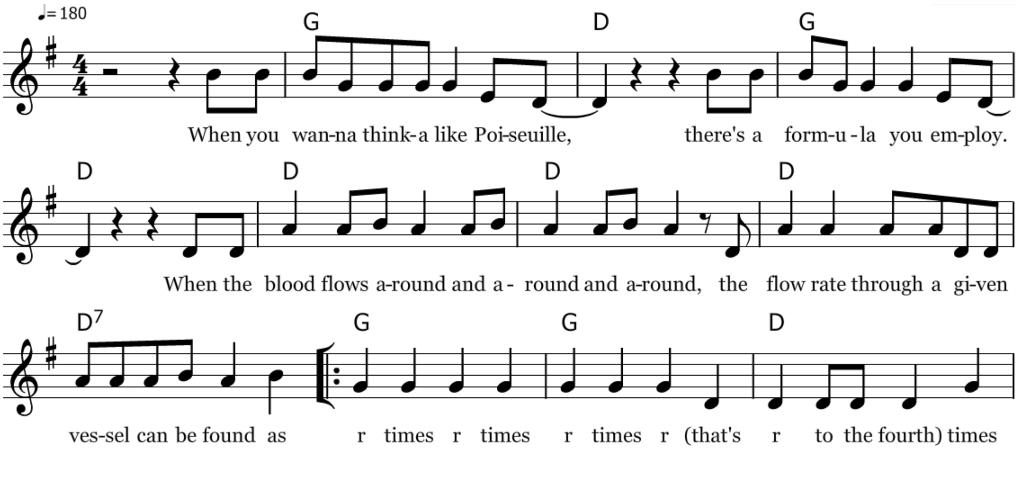
In this manner, over several quarters, the lead author created five additional math-themed songs for his physiology courses. Songs were intended to be brief – and thus may be considered “jingles” rather than full songs – as well as clear, pleasant, and easy to sing. These goals were not 100% compatible with each other; for example, changing the above-mentioned phrase to “radius times radius times radius times radius” would improve its clarity but would compromise its musicality. Since some ambiguities are unavoidable, we use them to spark class discussions, as exemplified by the questions provided in the Appendix.

Results and Discussion

Part 1: Students' overall reactions to physiology songs

As part of the lead author's teaching, he routinely inserts content-rich songs into lectures. Our initial assessments of this approach were usually limited to multiple-choice surveys asking students whether they liked the songs and/or whether the songs helped them learn. Data from three different classes of physiology students are shown in Figure 2. These data suggest that most students (60 to 67%, depending on the course) find the songs helpful or very helpful, as opposed to neutral (18% to 37%) or unhelpful or very unhelpful (0% to 12%).

Additional analysis of surveys from these courses suggested an important caveat regarding the Figure 2 data: students' ratings of the songs might reflect their overall satisfaction with the course content and/or instructor as much as or moreso than their specific opinions of the songs per se. That is, the more the students like the course content and/or instructor, the more highly they will tend to rate songs (and other tools), irrespective of the specific merits of the songs (or other tools). This possibility first occurred to us when we found strong correlations between SSC Biology 241 students' ratings of the songs and their ratings of other teaching tools, with R^2 values of 0.88 (songs vs. kinesthetic movements), 0.39 (songs vs. worksheets), and 0.48 (songs vs. labs). We had previously assumed that students' reactions to songs would be independent of their reactions to other course tools because, for example, the songs were written by the course instructor (G.J.C.), whereas the lab exercises were taken from a standard mass-published lab manual.



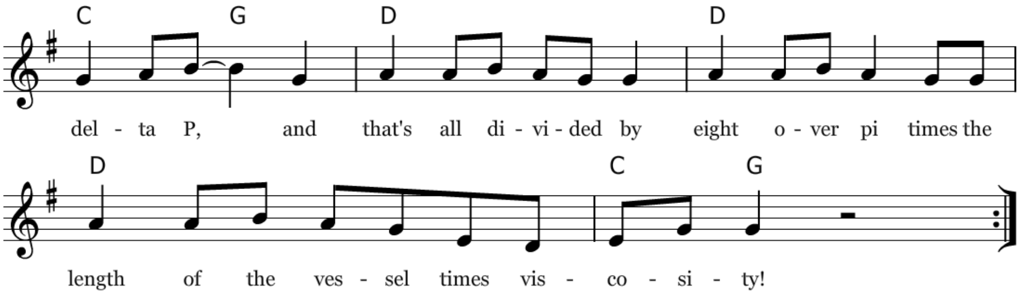


Figure 1. **Sheet music for the jingle "Poiseuille's Law of Laminar Flow."**

Having noticed these correlations retrospectively at SSC, we then prospectively tested their occurrence in two physiology courses (Biology 241 and Biology 352) at a different institution (UWB). These courses used somewhat different teaching tools and multiple lab instructors, but the same classroom lecturer (G.J.C.). We again found highly significant correlations between students' perceived usefulness of the songs and their perceived usefulness of other tools (songs vs. in-class discussions: $R^2 = 0.16$, p=0.002; songs vs. study guides: $R^2 = 0.16$, p=0.003). Thus, "bleed-over" of overall satisfaction into ratings of songs (or any specific course component) likely biases the latter. Additional support for this interpretation comes from surveys from the same course (Biology 220) taught by G.J.C. two consecutive quarters in a row at the same institution (UWS). From the first quarter to the second quarter, students' ratings of the course content rose from 3.2 to 3.8 on a 5-point scale, and their ratings of the instructor's contribution to the course rose from 3.0 to 4.0; likewise, the percentage of music-related survey comments that were positive (as opposed to mixed or negative) climbed from 33% (46 of 140) to 61% (11 of 18). While other explanations for these quarter-to-quarter changes cannot be ruled out, the data are consistent with the idea that students' ratings of specific instructional features (such as music, in our case) are biased by their overall opinion of the course content and/or instructor. This argument has previously been advanced (though not about music in particular) by others such as d'Apollonia & Abrami (1997) and Young (2006). A practical implication is that any class's ratings of songs should be interpreted in the context of its overall "baseline" satisfaction with the course. Several previous studies of educational STEM songs (McLachlin, 2009; Grossman & Watson, 2015; Weinhaus & Massey, 2015; Yee Pinn Tsin, 2015), including our own (Crowther & Davis, 2013), have omitted this important context. Future studies could address this issue by reporting students' ratings of music alongside their ratings of other aspects of the course. Students who give a course's music a 4 on a 1-to-5 scale might be considered pro-music if they give 3s to most other parts of a course, but perhaps not if they give 4.5s to most other parts.

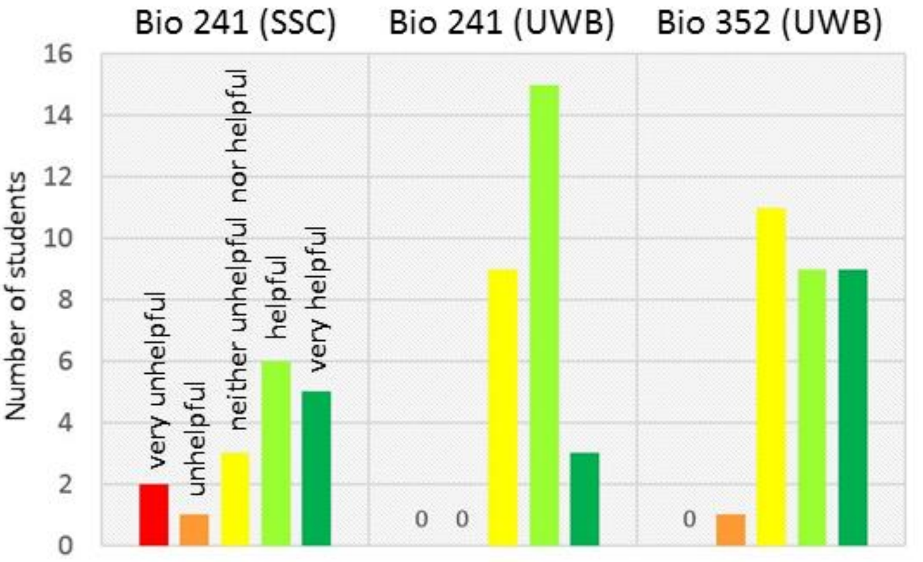


Figure 2. **Responses of three different physiology classes to the question "To what degree did the songs used in class help you learn the class material?"** *Possible answers were: very unhelpful (red), unhelpful (orange), neither unhelpful nor helpful (yellow), helpful (light green), and very helpful (dark green).*

Part 2: Students' detailed reactions to physiology songs

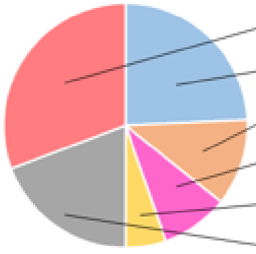
Having noticed the limitations of typical survey results like those presented above, we desired more extensive and therefore more valuable feedback to inform our development of songs as biology teaching tools. Fortunately, such feedback was available via generic end-of-course evaluations completed by 433 of the 573 UWS students enrolled in Biology 220 in the spring quarter of 2014. Of these 433 students, 348 answered one or more of the open-ended questions following the multiple-choice questions (see Methods); of these 348, 140 students (40%) commented specifically on the songs used during lectures despite the lack of a song-related prompt and the limited class time devoted to the songs (2% of total lecture time). A summary of these song-specific comments is given in Figure 3. Remarkably, despite the lack of a song-related prompt, many students made specific suggestions for improving the songs' usefulness. The three most common suggestions (explicit or implied) were (C) class time devoted to songs should be carefully limited (13% of students commenting on the songs), (D) connections between song lyrics and lectures should be made more obvious (10% of students), and (E) songs should be repeated for maximum impact (6% of students). Examples of each type of comment are given in Figure 3.

A song-specific survey completed by 85 students in this same class (see Methods) resulted in two additional findings of note. First, 84% of these students said that any in-class musical exercises should be limited to 6 minutes or less, thus confirming the prevalence of theme C above (Figure 4). Second, among the six featured songs, the two mathematical songs ("Surface Area to Volume Ratio" and "Fick's Law of Diffusion") received the highest and 3rd-highest ratings, respectively (Figure 5).

Part 3: Development of a suite of math-themed physiology jingles

Intrigued by the students' possible preference for math-themed songs, and now recognizing the need for clearer songs that reinforce key course content in more obvious ways (theme D above), the lead author developed additional songs covering mathematical relationships central to animal physiology (Table 2). Each song lasts less than one minute, perhaps qualifying it as a "jingle" rather than a full song; this brevity enables concise in-class interludes (theme C). Lyrics, sheet music, and simple online recordings are all now publicly available (at the URLs listed in Table 2) to facilitate subsequent recall and practice (theme E). Thus, the development of these jingles has been informed by students' feedback, as well as checked for accuracy and clarity by a second physiologist (J.L.B.). Brief notes on each jingle are included below; possible questions to ask students about each jingle are included in the Appendix.

"Cardiac Output and Pulmonary Ventilation." This jingle compares the analogous equations for calculating cardiac output and calculating pulmonary ventilation. Parallels in the two equations are emphasized by the parallels in the verses, with only a few words changed between the cardiac output verse and the pulmonary ventilation verse. For cardiac output: "Volume moved per <u>beat</u>/Times number of <u>beats</u> per minute/Equals volume of <u>blood</u> per minute;/That's all this equation has in it!" For pulmonary ventilation: "Volume moved per <u>breath</u>/Times number of <u>breaths</u> per minute/Equals volume of <u>air</u> per minute;/That's all this equation has in it!" Our hope is that if a student can recall either one of the two equations, the other will be easy to retrieve.



Theme	**Sample student comments (reproduced as written)**
A	• "I know some people found it annoying that you sang, but I loved it! I really think music is a good way to memorize things- I still remember the water cycle song I learned in 7^{th} grade!" • "The music was really helpful. It helped me to cement certain concepts in my mind."
B	• "The songs wasted valuable class time that could be used actually explaining concepts." • "Stop singing songs, they are a waste of my time, especially when we are behind."
C	• "I think shorter little jingles would be much more helpful. They're easier to remember and more [succinct]." • "The songs that the professor tried to teach us, they take up way too much class time for how helpful they are and I feel like I would actually more interested if we were treated like adults and presented the course material in a straightforward manner instead of trying to make it 'fun'. It's not."
D	• "Many of the songs used did not help us learn the material better, it was simply a class activity that was about the subject we were learning but did not work to enhance our understanding or help remember the material better." • "Make sure to prime the students with what the take home message of the song is before singing."
E	• "Songs … were a good idea but its hard to really learn from them if you just sing them one time. I can't remember lyrics to any song I heard just once." • "Songs were good, in particular the SA:V ratio. However, that's the only one I can really remember. Having songs to help us remember the material is only beneficial if we can remember them-maybe reference them a bit more during other lectures if they're relevant."

Figure 3: **Comments about physiology songs from UWS Biology 220 students.** (*140 students who commented specifically on songs used in class were classified as shown. Percentages sum to >100% because five students fit into two categories).*

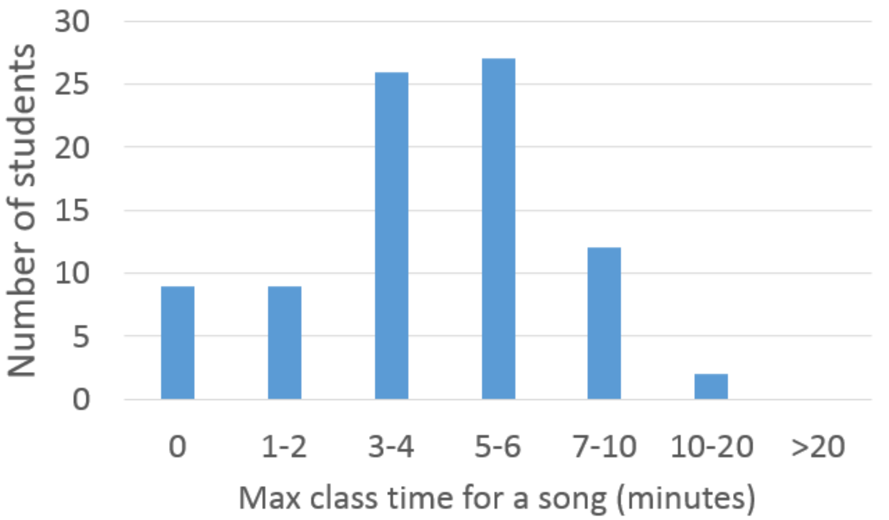


Figure 4. **Responses of UWS Biology 220 students (N=85) to a question on the maximum amount of class time that should be devoted to a content-based song.**

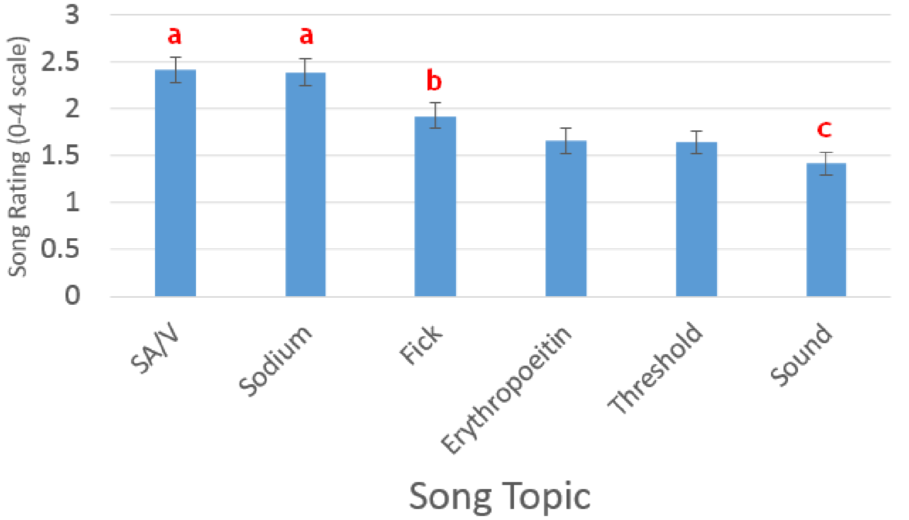


Figure 5. **Ratings of UWS Biology 220 students (N=82) of six songs on a 0-to-4 scale.** *Error bars represent standard errors of the mean (SEM). Means with different letters are significantly different from each other ($p < 0.01$) according to paired t-tests with a Bonferroni correction for multiple comparisons. SA/V and Fick are the two song topics on mathematical relationships.*

Table 2

Math-Themed Physiology Jingles Developed During This Study

Title (Duration)	Equation(s)	Explanation
Cardiac Output and Pulmonary Ventilation (~50 sec).	$CO = SV * HR$ $PV = TV * RR$	Cardiac output (CO) and pulmonary ventilation (PV) are both calculated in the same way: the volume pumped (stroke volume [SV] or tidal volume [TV]) is multiplied by the frequency of pumping (heart rate [HR] or respiratory rate [RR]).
	http://faculty.washington.edu/crowther/Misc/Songs/2equations.shtml	
Fick's Law of Diffusion (~40 sec)	$Diffusion\ rate = \frac{\Delta P * A * k}{D}$	Diffusion rate is directly proportional to the concentration gradient (ΔP, for partial pressures of gases) and surface area (A), and is inversely proportional to diffusion barrier thickness (D).
	http://faculty.washington.edu/crowther/Misc/Songs/fick.shtml	
In-Lever, Out-Lever (~50 sec)	$MA = \frac{L_i}{L_o}$	For loads moved by muscles, the mechanical advantage (MA) equals the length of the in-lever (L_i) divided by the length of the out-lever (L_o).
	http://faculty.washington.edu/crowther/Misc/Songs/station8.shtml	
The Nernst Equation (~40 sec)	$E_{ion} = \frac{58\ mV}{z} log_{10}\left(\frac{[ion]_{out}}{[ion]_{in}}\right)$	An ion's equilibrium potential (E_{ion}) can be calculated from its concentrations outside and inside the cell ($[ion]_{out}$ and $[ion]_{in}$) and its electrical charge (z).
	http://faculty.washington.edu/crowther/Misc/Songs/nernst.shtml	
Pee Values (~40 sec)	$E = F + S - R$	In the kidney, a substance's excretion rate (E) equals its filtration rate (F) plus its secretion rate (S), minus its reabsorption rate (R).
	http://faculty.washington.edu/crowther/Misc/Songs/pee.shtml	
Poiseuille's Law of Laminar Flow (~40 sec)	$Q = \frac{r^4 * \Delta P}{\frac{8}{\pi} * L * \eta}$	The rate of blood flow through a blood vessel (Q) depends most strongly on the radius of the blood vessel (r). Q also depends on the hydrostatic pressure gradient (ΔP), blood vessel length (L), and fluid viscosity (η).
	http://faculty.washington.edu/crowther/Misc/Songs/poiseuille.shtml	
Surface Area-to-Volume Ratio (~55 sec)	$\frac{SA}{V} = \frac{6L^2}{L^3} = \frac{6}{L}$	Animals' metabolic rates reflect a balance between intake of nutrients via their surface area (SA) and the use of these nutrients by their internal volume (V). For a hypothetical cube-shaped animal, as body length (L) increases, V increases more rapidly than SA.
	http://faculty.washington.edu/crowther/Misc/Songs/SAtoV.shtml	

"Fick's Law of Diffusion." When equations are expressed concisely, the meaning of the abbreviations may be forgotten (Watkins & Elby, 2013). "Fick's Law of Diffusion" addresses this issue by presenting the abbreviations in the first half of the jingle, then spelling out the full terms (in the same order) in the second half. Thus, "delta P" corresponds to "pressure difference," "A" corresponds to "surface area," "k" corresponds to "the constant k," and "D" corresponds to "diffusion barrier."

"In-Lever, Out-Lever." Students generally remember that mechanical advantage (MA) is equal to a ratio involving the in-lever (L_i) and the out-lever (L_o), but they often flip the numerator and denominator. This jingle helps them remember that MA equals L_i divided by L_o and points out that a change in either one can improve the mechanical advantage: "Elongate the in-lever, shorten up the out."

"The Nernst Equation." This jingle does not present the terms of the equation as one would write them out from left to right; rather, it starts with the ratio of extracellular and intracellular ion concentrations because this is the core of the equation – an ion's equilibrium potential (E) reflects its relative concentrations outside and inside the cell – and the other terms should not distract from that.

"Pee Values." In studying the kidney, many students struggle with the terms *filtration*, *reabsorption* and *secretion*. In particular, they often do not know whether each of these processes moves substances from the blood to the pre-urine or vice versa. They will keep these straight if they understand the jingle's equation, which conveys that filtration and secretion move substances *into* the pre-urine (for excretion) while reabsorption does the opposite.

"Poiseuille's Law of Laminar Flow" (Figure 1). The repetition of "r times r times r times r" emphasizes the surprising fact that blood flow rate is proportional to vessel radius (r) raised to the 4^{th} power. (In addition, the rhyme with "employ" helps students pronounce the French surname "Poiseuille.")

"Surface Area-to-Volume Ratio." This jingle references the formulas for the surface area and volume of a cube: $6L^2$ and L^3, respectively, where L is the length of a side of the cube. These formulas should be written out explicitly to avoid confusion (e.g., "Six L to the two" might not otherwise be understood as $6L^2$). Also, the alliteration of "large" and "low" in the line "If you're large, it's low" reminds students to group these two adjectives together: a large body size implies a low surface area-to-volume ratio.

Advice on Implementation

Based on the data presented in Part 2 and past experience deploying music in the classroom, we recommend that physiology instructors who wish to use a jingle should consider the following. Though some instructors consider music to be a fun way of introducing new topics (Crowther et al., 2016), we usually use songs as recaps or extensions of already-covered topics, so that students have some context in which to interpret the song lyrics (theme D above). Instructors should facilitate multiple passes through a jingle (theme E), perhaps by using it in class and also encouraging out-of-class, web-aided practice. Non-singing instructors may wish to recruit musically inclined colleagues, teaching assistants, or student volunteers. In addition, rather than assuming that a jingle "speaks for itself," instructors should help students unpack the highly compact lyrics (theme D). Finally, as with any other aspect of a lecture, advance rehearsal of jingles will help ensure that valuable class time is used efficiently (theme C).

Conclusion

Obviously, further evaluation will be necessary to assess the effectiveness of the seven jingles listed in Table 2. These jingles are now being evaluated by hundreds of students NOT taught by the lead author; we look forward to reporting these results in a future publication.

While this study focused on college physiology courses due to our expertise and current teaching assignments, our work may be informative to any high school or college-level efforts (e.g., in a math class) to teach math with content-rich music. In particular, we believe that college students' apparently strong preference for very short jingles is an important finding, partly because it contrasts with the extended length of most commercially available math songs for this age group, as catalogued at SingAboutScience.org (Crowther, 2012b). Indeed, it is notable that two of the only studies to demonstrate a positive impact of content-rich math music on test performance (VanVoorhis, 2002; Lesser et al., 2014) used jingles rather than full-length songs as their intervention.

In summary, while math remains a considerable challenge for many biology students, brief content-rich jingles may render it less dreary and more accessible. The examples presented here may, at the very least, provide engaging interludes that are minimally disruptive to existing curricula.

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Appendix
Sample Questions to Ask Students about the Physiology Jingles

"Cardiac Output and Pulmonary Ventilation"

Questions: (1) The terms *cardiac output*, *stroke volume*, *heart rate*, *pulmonary ventilation*, *tidal volume*, and *respiration rate* are not included in the jingle's lyrics, but their definitions ARE included. Which definitions go with which terms? (2) How do these variables change when you start performing aerobic exercise?

Answers: (1) "Volume of blood per minute" is cardiac output. "Volume moved per beat" is stroke volume. "Number of beats per minute" is heart rate. "Volume of air per minute" is pulmonary ventilation. "Volume moved per breath" is tidal volume. "Number of breaths per minute" is respiration rate. (2) All of these values increase during aerobic exercise.

"Fick's Law of Diffusion"

Questions: (1) Which term of the equation reflects a concentration gradient, which is necessary for diffusion? (2) What does the "constant" k depend on?

Answers: (1) Pressure difference (delta P) refers to a difference in the partial pressures of a gas, and thus reflects a concentration gradient. (2) "Constant" k depends on the temperature, the size of the molecule that is diffusing, the specific medium through which it is diffusing (water? air?), etc.

"In-Lever, Out-Lever"

Questions: (1) What units does Mechanical Advantage (MA) have? (2) What range of values can a Mechanical Advantage have? (3) Mechanical Advantage can also be calculated from the force in (F_i) and force out (F_o), or from the velocity in (V_i) and velocity out (V_o). How do those formulas compare to the one presented in the jingle?

Answers: (1) MA is unitless; the units of the numerator and denominator cancel. (2) In theory, mechanical advantage can be anywhere from just above 0 to far above 1. (3) MA is also equal to F_o divided by F_i and to V_i divided by V_o.

"The Nernst Equation"

Questions: (1) What is ion valence? (2) What units are carried by the equilibrium potential (E)? (3) What does the value of E mean?

Answers: (1) Ion valence is the charge carried by an ion, such as minus-1 or plus-2. (2) E, an electrical potential, generally is reported in units of millivolts. (3) E is the electrical gradient across the membrane needed to perfectly counterbalance any concentration gradient, such that there is no net movement of the given ion from one side of the membrane to the other.

"Pee Values"

Questions: (1) Does secretion of a solute by the kidney increase or decrease the rate at which it is excreted? (2) Is it possible for the excretion rate of a solute to be 0? If so, how?

Answers: (1) Secretion of a solute increases the solute's excretion rate. (2) Yes, this is possible. If the filtration, secretion, and reabsorption rates are all 0, then the excretion rate will be 0 as well. (This is generally true for proteins in the blood.) Alternatively, if the reabsorption rate is equal to the sum of the filtration rate and the secretion rate, the excretion rate will be 0. (This is generally true for glucose in the blood.)

"Poiseuille's Law of Laminar Flow"

Questions: (1) How does vessel radius (the "r" in the song) relate to resistance to blood flow? (2) What is delta P here? Is this the same delta P that is in Fick's Law of Diffusion? (3) Can you rearrange the equation so that pi is in the numerator?

Answers: (1) Resistance to flow (often abbreviated with a capital R) is proportional to radius to the 4^{th} power. (2) Here delta P refers to a difference in hydrostatic pressure over the length of the vessel. It is not the same as the delta P in Fick's Law of Diffusion. (3) The equation can be rewritten as: Flow = $(\pi * r^4 * \Delta P)/(8 * L * \eta)$.

"Surface Area-to-Volume Ratio"

Question: (1) If we were to assume that an animal were spherical, rather than cube-shaped, would SA/V be similarly affected by body size?

Answer: (1) Yes. The surface area of a sphere equals $4 * \pi * r^2$, where r is the radius. The volume of a sphere equals $(4/3) * \pi * r^3$. The surface area-to-volume ratio is 3/r, which decreases as r increases. Thus this ratio decreases with increasing size, regardless of whether the object is cube-shaped or spherical.

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