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Songwriting to learn: how high school science fair participants use music to communicate personally relevant scientific concepts

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ABSTRACT
One STEAM (STEM + Arts) strategy is to supplement traditional STEM instruction with music. Using music could provide the dual benefits of (1) making STEM content more accessible and (2) enhancing students’ engagement in the learning process. Here we explore the extent to which music-oriented high school students achieve these two benefits when they participate in ‘Songwriting To Learn’, a possible variation on the Writing To Learn (WTL) model of instruction. We analysed 81 artist statements, collected over 12 years at an annual science fair, in which students described their music compositions and the compositions’ connections to science. Rather than simply reporting scientific facts in song lyrics, these students used an impressive variety of musical elements (Genre, Instruments, Lyrics, and Structure [i.e. chords, dynamics, melody, rhythm]) as metaphors or symbols for science-related elements (Scientific Topic, Conveying Information, Affect, Personal Story, Scientific Story). Many students demonstrated a sophisticated attention to musical details and nuances, consistent with their frequent self-identification as musicians and/or music fans. Moreover, in composing and performing songs, these students fulfilled some of the key criteria by which scientific identities are developed, including the forging of personal connections to science. By writing songs about science, students may use their practice-linked identities in the domain of music to express their growing understanding in the domain of science.

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Arts integration; ArtSci; content-rich music; practice-linked identity

Introduction: STEAM, music, and (Song)writing to learn

A recent trend in STEM education has been the merging of STEM with the arts, or STEAM (Science, Technology, Engineering, Art, Mathematics). However, there is no clear consensus on whether STEAM is efficacious or how to best balance Arts and STEM content (Jolly, 2014; Robelen, 2011). Advocates argue that the arts can develop skills such as verbal literacy (Piro, 2010), outside-the-box thinking (Land, 2013), aesthetic design (Bequette & Bequette, 2012) and collaboration and community engagement (Guyotte, Sochacka, Costantino, Kellam, & Walther, 2015) that are not fully developed in traditional STEM curricula but that are necessary components of, or complementary to, real-life STEM work.

Music has received some attention among the many possible ways to connect STEM and the arts. The stated purposes of these endeavours are primarily (1) to communicate specific STEM
content and (2) to increase students’ engagement in the learning process (Crowther, 2012; Governor, Hall, & Jackson, 2013). First, music is sometimes touted as an efficient means of content delivery. This is usually tied to music’s role as a mnemonic device, which helps students remember and recall information (Crowther, Williamson, Buckland, & Cunningham, 2013; Thaut, Peterson, McIntosh, & Hoemberg, 2014). STEM educators often rewrite songs with discipline-specific lyrics (Dickson & Grant, 2003; Dougherty, 2008; Hermanns, Lilly, Wilson, & Russell, 2012; Lesser, 2014; McLachlin, 2009; Pye, 2004) to make disciplinary content easier to learn and remember. In this situation, a familiar tune serves as a convenient template for storing new science information. In addition, song lyrics can be dissected and analysed to promote understanding of content (Governor et al., 2013; Jurmu, 2005). This kind of engagement gives students the opportunity to revisit lecture content in an alternative form (i.e. song lyrics), and, therefore, to encounter and address points of confusion (Governor et al., 2013). In each of these examples, the goal is student content learning that can be assessed with traditional instruments, such as exams.

Second, regarding engagement, music is a fun (Lesser & Pearl, 2008) way to increase students’ enjoyment of STEM subjects such as biology (Crowther, Davis, Jenkins, & Breckler, 2015; Grossman & Watson, 2015), chemistry (Pye, 2004), computer science (Dougherty, 2008), mathematics (Lesser, 2014), physics (Dickson & Grant, 2003), and statistics (Lesser, Pearl, & Weber, 2016). Even more fundamentally, music is central to young people’s identities, serving as a marker of group affiliation and being associated with specific clothing choices, cultural values, and so on (Arnett, 1996; Bennett, 1999, 2000; Brake, 1985). Thus, proponents of ‘hip-hop education’ seek to use music as a bridge by which students can make personal connections to STEM (Emdin, 2010).

While most of the above-cited work concerns music created by STEM instructors and professional musicians, some scholars have also noted the potential for learning at the intersection of music and science when students create their own songs. As part of a masters thesis in science communication, McFadden (2013) not only studied middle school students’ responses to a pre-made song parody, but also solicited student compositions via a ‘Science Idol’ competition. Gershon and Ben-Horin (2014) explored the ways in which student-generated music facilitates creative learning experiences that align with inquiry-based education. They argue that music is relevant to science in several respects. For example, by incorporating sensory and emotional cues, music may provide a more holistic perspective on science than traditional lectures do. Moreover, developing original music involves risk-taking, collaboration, and becoming ‘lost in inquiry’ (p. 6), and thus mirrors the experience of authentic scientific investigation. Just as ‘mistakes’ get incorporated into emerging musical compositions, so too do unexpected detours get incorporated into the paths of scientific inquiries (Gershon & Ben-Horin, 2014).

If the students themselves produce STEM music (Emdin, Adjapong, & Levy, 2016; Gershon & Ben-Horin, 2014; Grossman & Richards, 2016), rather than passively consuming it, any impacts of music on content processing and/or engagement might be especially profound, consistent with the position of Create (formerly Synthesis) atop Bloom’s revised taxonomy of cognitive processes (Krathwohl, 2002) and the critical role of Elaboration (sometimes called Expansion or Extension) in the 5E inquiry cycle (Bybee et al., 2006). In fact, student songwriting could be considered a form of Writing To Learn (WTL), which holds that much of the work of constructing understanding occurs during (rather than before) the writing process (Crowther, Ma, & Breckler, 2017; Reynolds, Thaiss, Katkin, & Thompson, 2012; Rivard, 1994). WTL brings to light both gaps in understanding and personal connections to the material (Balgopal & Wallace, 2009), paralleling the possible benefits of STEM music noted above. Similarly, two types of WTL assignments are considered especially efficacious: content-focused ones asking students to formulate a reasoned argument about evidence, and epistemic ones asking them to reflect on the nature of their personal knowledge and its applications (Reynolds et al., 2012).
**STEM content: constructivist songwriting**

Ideally, STEM education is informed by the spirit of constructivism. Constructivism views learning as a dynamic process in which students come to learning contexts with previous understandings informed by their unique histories and experiences, and then build upon those understandings with new information and experiences. As such, designing learning opportunities that take this into account is key for engaging students. One example, as described by Sanders (2008), is integrative STEM activities that ‘provide a context and framework for organizing abstract understandings of science and mathematics and encourage students to actively construct contextualized knowledge of science and mathematics, thereby promoting recall and learning transfer’ (p. 23). Furthermore, constructivist learning is rarely limited to the construction of knowledge per se; it often includes the construction of ‘personally meaningful products’ (Rusk, Resnick, & Cooke, 2009, p. 18), a flavour of constructivism known as constructionism (Papert & Harel, 1991).

When students do construct their own STEM songs, how do they communicate the STEM content that they are learning? One possibility is that musical communication of STEM content is simply a matter of converting STEM material into song lyrics. In an unusually thorough paper based on a doctoral dissertation, Governor et al. (2013) go so far as to define science-content music as ‘designed to teach and explain science-related concepts through verse’ (p. 3118; emphasis added) and also state, ‘songs carry content in lyrics’ (p. 3119; emphasis added). Similar views can be found in less comprehensive papers (Maute, 1987; Smolinski, 2011).

While it is obvious that STEM content can be conveyed conveniently via song lyrics, other features of music (e.g. rhythm, melody, choice of instruments) could also represent content. The emerging field of data sonification has already provided many examples of how data can be represented musically (Beans, 2017; St. George, Crawford, Reubold, & Giorgi, 2017). For example, multiple trends in atmospheric CO₂ levels (seasonal cycling superimposed on a long-term trend of gradual increase) are captured in a short electronic music piece produced as part of a community outreach effort (University of Washington Department of Atmospheric Science, 2016). Such an approach may also be used to represent general concepts or trends rather than specific data. For instance, in a song about the neurotransmitter noradrenaline, Hermanns et al. (2012) use a fast tempo to signal noradrenaline’s involvement in flight-or-flight responses; in a song about the states of matter, They Might Be Giants (2009) use different tempos to indicate the different molecular motions of solids, liquids, and gases; and in a song about amino acids, Crowther and Davis (2013) use high and low pitches to represent high and low pH, respectively. On the whole, however, such considerations of meanings embedded in sounds (rather than in lyrics per se) are relatively rare. Many authors who mention non-lyrical aspects of STEM songs do so only to note that these other features make the lyrics easier to memorize (Lesser et al., 2016; McLachlin, 2009).

Given that music is a multifaceted medium including more than lyrics, our Research Question #1 (RQ1) was the following: how do students’ musical compositions represent STEM content? That is, do they mostly encapsulate this content as song lyrics, or do they exploit other aspects of music as well?

**Engagement: development of practice-linked scientific identities**

Student engagement can be defined as the convergence of interest, effort, and concentration (Newmann, Wehlage, & Lamborn, 1992) or as ‘active student involvement on learning tasks that are meaningful, relevant, and motivating to the student’ (Burden & Byrd, 2013, p. 186). Ideally, students will come to see entire scientific disciplines as interesting, relevant to their lives, and worthy of great effort; in other words, they will develop scientific identities, in which they see themselves as ‘the kind of person who engages in science’ (Brickhouse, Lowery, & Schultz, 2000, p. 441). Fostering scientific identities is a major goal of recent science education initiatives such as the Next Generation Science
Standards (NGSS) in the USA (NGSS Lead States, 2013). Scientific identities are developed partly via engagement in scientific practices, e.g. constructing knowledge through hands-on activity (Kafai, 2006). This close connection between practice and identity is captured in the phrase ‘practice-linked identity’ (Nasir & Cooks, 2009). While the NGSS do not include this exact phrase, the concept is implicit in NGSS’s identification of eight key Science and Engineering Practices: (1) ask questions; (2) develop and use models; (3) plan and conduct investigations; (4) use and interpret data; (5) use math and computational thinking; (6) construct explanations; (7) argue from evidence; and (8) obtain, evaluate, and communicate information. These practices are considered central to the professional practice of science, yet within the reach of K-12 students (National Research Council, 2012).

Nasir and Hand (2008) offer a detailed model of how students develop a practice-linked identity in science or other domains. To start with, students need to have access to a content domain and need to develop a personal identification with that domain. Two other key contributors to a practice-linked identity come with that access: the opportunity to take on roles integral to the practice, and the opportunity for self-expression (Nasir & Hand, 2008). The practice-linked identities emerging from such experiences allow students to see themselves as people who engage in science, art, or another domain of practice.

It is worth noting that this intimate connection between engagement and identity, as proposed by Nasir and Hand (2008), is fully consistent with the above-mentioned lens of constructivist learning. A sociocultural understanding of identity development is fundamentally constructivist in that, as students come to school contexts, they bring with them a whole host of interests, experiences, and perspectives and as such, they not only acquire certain skills and knowledge but become particular kinds of learners in a professional community (Lave & Wenger, 1991).

One example of identity-linked science learning with an arts component is an after-school programme on urban heat islands (UHIs) described by Calabrese Barton and Tan (2010). Here students measured local variations in temperature and explained how natural and human-made features might cause these variations. The experience of producing science-driven documentaries and sharing them with members of their community instilled a sense of personal agency in students and supported the development of their scientific identities.

We thus arrive at the following problem. Music is a powerful medium for many young people, yet, notwithstanding the insights of Gershon and Ben-Horin (2014), composing music is generally considered fundamentally different from practicing science. Therefore our Research Question #2 (RQ2) was this: to what extent can songwriting help students create practice-linked scientific identities? In this area, our work takes inspiration from Emdin (2011), who has explained how the medium of hip-hop music can give students a voice in science classrooms where they previously were silent, and thus empower them as contributors to scientific discourse.

We addressed both RQ1 and RQ2 primarily through the analysis of archival data from the Student Bio Expo, a unique science fair that allows students to present their work in a variety of media, including music (Chowning, 2002). In particular, we analysed 81 Expo participants’ artist statements in which they explained their musical compositions, often commenting on both their processing of STEM content and their level of engagement with their topics. Our results suggest the extent to which these students were able to achieve music’s hypothetical benefits of (1) learning specific content and (2) engaging fully with that content.

**Methods**

We begin our Methods by describing the science fair, the Student Bio Expo, from which we collected our data, and the artist statements that we used as the basis of our thematic analysis. We used the thematic analysis to identify scientific and musical elements, their relative frequencies, and the connections students forged between them.
The student bio expo

Each year, students in grades 9–12 attending Seattle-area schools are invited, through their teachers, to participate in the Student Bio Expo, an event described in detail by Chowning (2002) and NWABR (2018). Student participation is required in some classes and optional in others. This type of learning merges traditional, formal, academic activities with non-traditional, informal, out-of-school ones. For example, most students receive guidance from both their regular science teacher and an external scientific mentor provided by the event host (NWABR). Students submit both a traditional science content paper and creative products such as original music. They present their work both in school and outside of school at the Expo itself (Chowning, 2002; NWABR, 2018).

Student projects must be related to biotechnology or biomedicine, but can be completed in any of 13 categories spanning a variety of media: art; career pathways; creative writing; drama and dance; journalism; lab research; molecular modelling; multimedia; music; SeaVuria (for global health collaborations between students in Seattle, Washington, USA and Vuria, Kenya); SMART Teams (Students Modeling A Research Topic; for creating molecular models); teaching; or website (Chowning, 2002). According to data provided by NWABR, the Expo includes approximately 250–350 students from 15–25 high schools in the greater Seattle area. About 3% of participants (10 per year) complete a project in the music category. Most participants in the Expo are seniors (45%), juniors (29%), or sophomores (23%) rather than freshmen (3%). Participants’ races/ethnicities are: 20% Asian, 5% Black, 60% Caucasian, 4% Hispanic, 1% Native American, 1% Pacific Islander, 8% Mixed, 2% Other.

Music entries

Students could submit music projects as individuals or in groups. Each student or group of students in the music category of the Expo were required to submit several materials to the event host (NWABR; see Appendix 1 of the online supplement for the complete instructions): a science background paper, a musical score, and an audio or video recording (one per group); and individual artist statements, connections and collaborations statements, and annotated bibliographies (one per individual). The event host shared these archival data with us after we obtained Human Subjects Division approval from the University of Washington (studies #44216 and 45835). For the artist statements—the focus of the present study—students were asked to ‘provide insight into the work. This could include answering the following questions: What provided the inspiration for the work? Why was the work made? What was the purpose? What are ideas that are conveyed? What references are made? What do you hope listeners will get out of the piece? What did you learn about science from doing this work? If you worked with a group, why was a group needed? What role did each member of the group fulfill?’.

The 81 available artist statements, submitted between 2004 and 2015, represented 66 distinct music projects by 92 students, 48 of whom worked in teams of two or three (but each submitted her/his own statement starting in 2008). Statements ranged in length from 178 to 1806 words (median words = 530; mean ± SD words = 612 ± 331).

Thematic analysis of artist statements

We made the methodological choice to perform a limited analysis of a relatively large sample of student projects, rather than a more extensive analysis of a smaller number of projects. This choice was dictated in part by our limited access to students and materials. Since we did not have access to most students’ musical performances, or to the students themselves, we felt that a broad sampling of artist statements, representing a wide range of student experiences, would be most informative. In addition, this broad sampling was attractive in that it would limit concerns that specific projects were cherry-picked to illustrate preordained conclusions. We believe that the influence of individual researchers’ biases was also reduced via frequent critical discussions among the four coauthors, who
began the project with different priorities and assumptions. Finally, since each project addressed a different scientific topic—some more fact-based and some more ethical or personal—we did not formally assess each project’s scientific accuracy.

To address our two principal research questions, we employed thematic analysis (Boyatzis, 1998) to code scientific and musical elements expressed in the artist statements (as in Chang, 2015). Two members of the research team (S.J.W. and G.J.C.) read artist statements independently to identify relevant themes. We then met to create and refine coding categories (see below) collaboratively (Smagorinsky, 2008). Finally, we used the refined list of categories to code a second selection of statements independently.

To assess inter-rater consistency, Cohen’s kappas were calculated throughout the coding process (Cohen, 1968). These reliability checks provided opportunities for the two coders to clarify the coding scheme and resolve disagreements through conversation. With one exception, all kappas for events occurring in ≥5% of artist statements exceeded 0.5, indicating moderate-to-strong agreement among the coders (Appendix 2).

**RQ1: how do students’ musical compositions represent STEM content?**

We explored this research question by identifying and coding connections between scientific elements and musical elements of the artist statements. We define a Science-Music connection as a pairing between any one of the five scientific elements emerging from our iterative coding process and any one of the four emergent musical elements (20 pairings possible; Tables 1–5). For example,

<table>
<thead>
<tr>
<th>Musical element</th>
<th>Our definition</th>
<th>Examples (quotes from artist statements, corrected for clarity)</th>
<th>Count (% of all 81 artist statements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyrics</td>
<td>The lyrics include information about the topic.</td>
<td><strong>Topic: cancer</strong>&lt;br&gt;The lyrics of my rap go beyond the same old message that smoking is bad and causes cancer, to describe other types of cancer, the numerous ways it is contracted, and its mechanisms. I also describe cancer treatments, which do not simply involve taking small pills, but extend to unpleasant methods of detection and life changing surgery.</td>
<td>34 (42%)</td>
</tr>
<tr>
<td>Structure</td>
<td>The student explains how the structure (e.g. repeated elements, interplay between verses and chorus) conveys information about the topic.</td>
<td><strong>Topic: congenital amusia</strong>&lt;br&gt;This is the point of the piece that sounds the most cacophonous. This point represents how somebody afflicted with the worst case of congenital amusia might hear music.</td>
<td>25 (31%)</td>
</tr>
<tr>
<td>Instrument</td>
<td>The student explains how the instrumentation conveys information about the topic.</td>
<td><strong>Topic: Parkinson’s disease</strong>&lt;br&gt;Motion is difficult, assistance is needed with simple activities, and mental problems may arise when dealing with an advanced stage of Parkinson’s. There is an obvious difference between this part of the song compared to earlier. The once calm Hi-Hat is now full of buzzes and splashes, the crash cymbal is full of haphazard hits, and the addition of triangle adds a ringing panic.</td>
<td>8 (10%)</td>
</tr>
<tr>
<td>Genre</td>
<td>The student explains how the genre they chose conveys information about the topic.</td>
<td><strong>Topic: cancer</strong>&lt;br&gt;We did not include lyrics or any words because I thought it fit well just instrumentally to not only our topic idea but to the emotions of all the people who have lost a loved one from this ‘silent killer.’</td>
<td>3 (4%)</td>
</tr>
</tbody>
</table>

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*In this and all subsequent tables, some artist statements may have included more than one of the connections or traits listed.*
Scientific Topic-Genre is a connection between the scientific element of Scientific Topic and the musical element of Genre. An example of an artist statement excerpt coded as Scientific Topic-Genre is the following: ‘Although rap music often talks about killers with guns, my song presents different, but just as lethal killer—cancer.’ Here the code captures the student’s connection between the genre of rap and the lethality of cancer.

**RQ2: to what extent can songwriting help students create practice-linked scientific identities?**

Artist statements were also coded for the reason(s) that the student chose the music category as well as his/her reason(s) for choosing the specific scientific topic. In addition, since developing a scientific

<table>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 2.</strong> Scientific Topic is a scientific element in which students refer generally to their topic, without communicating specific information or telling a story about it.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Table 3.</strong> Scientific Story is a scientific element in which students describe the history of the topic.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Affect is a scientific element in which students attempt to elicit emotional or physical responses from the audience.

<table>
<thead>
<tr>
<th>Musical element</th>
<th>Our definition</th>
<th>Examples (quotes from artist statements, corrected for clarity)</th>
<th>Count (% of all 81 artist statements)</th>
</tr>
</thead>
</table>
| Lyrics          | The lyrics intend to elicit a physical or emotional response from the audience. | Topic: cancer  
My song is meant to be a positive and uplifting message for those who are walking the same path my family successfully walked. I want people to know that there is hope no matter how bad the diagnosis is, and not to give up ... The melody and the lyrics I wrote are there to inspire loved ones and people fighting cancer, to battle against the disease and win. | 9 (11%) |
| Structure       | The student explains how the structure (e.g., repeated elements, interplay between verses and chorus) elicits a physical or emotional response. | Topic: tardigrades (extremely stress-resistant animals)  
There will be somewhat randomly placed quiet spots, not really for scientific purposes, but more to build suspense ... Rapid key changes will occur in the movement, as the tardigrade is being attacked with massive heat, tearing apart at the skin and causing cryptobiosis yet again. | 21 (26%) |
| Instrument      | The student explains how the instrumentation elicits a physical or emotional response. | Topic: arson  
I have two separate guitar parts overdubbed, each played electrically with a slightly delayed effect put on them. This creates somewhat of a hollow, eerie effect, which is precisely what I had strived for. I don’t want to call it depressing, but it is certainly sobering. | 3 (4%) |
| Genre           | The student explains how the genre they chose elicits a physical or emotional response. | Topic: music’s effect on the brain  
I wanted to write an alternative rock song that switched between fast paced to a slower one. I wanted to do this because I wanted people to feel how the speed changes their mood ... I used metal/alternative rock sound because it was easier to incorporate some fortissimo, which is basically getting louder, and also fast-paced riffs and make people actually pay attention to every single note so they can keep up and I could grab their full attention. | 3 (4%) |

Results

RQ1: how do students’ musical compositions represent STEM content?

In Expo participants’ artist statements, we discerned five scientific elements—Conveying Information, Scientific Topic, Scientific Story, Affect, and Personal Story—and four musical elements—Lyrics, Structure, Instruments, and Genre.

Three of the five scientific elements—Conveying Information, Scientific Topic, and Scientific Story—refer to the factual content of the topic (Figure 1, Tables 1–3). In Conveying Information (Table 1), music represents information about the topic; Scientific Topic captures the way in which students named the focus of their research, without exploring it in depth (Table 2); and Scientific Story describes the history of the topic (Table 3). The last two scientific elements are more emotional: Affect, reflecting a student’s effort to elicit emotional or physical responses from the
Students explored these five scientific elements through four musical elements (Figure 1, Tables 1–5): Lyrics, the words of the song; Structure, the use of compositional devices like repetition, interplay between the verses and chorus, and emphases like crescendos; Instruments, in terms of which ones were used and the specific roles that they played in the song; and Genre, e.g. rap, bluegrass, orchestral, or rock.

**Factual content**
Most students sought to convey information through their songs, as shown by the high frequency of Convey Information in Figure 1. Conveying Information—Lyrics was the most frequent of all 20 possible Science-Music connections, occurring in 42% of artist statements (which is especially high considering that 35% of the music compositions were instrumentals without lyrics). For example, one student wrote,

> My goals for the lyrics of the song are to give an insight to Sickle Cell Anemia. I want to inform the listeners about the basics of the disease, such as how it is contracted, what it is, what it does to the body, how it can be treated, and how the treatments can affect a person. (also see Table 1)

Several artist statements conveyed a specific intent to teach their audience about the concepts they were researching. For example, ‘Hopefully from our song, people will learn the same information that we have obtained through days of research in only five minutes or so.’

Students used the Conveying Information—Structure connection in 31% of the artist statements. For example, one student described information about how a memory forms through...
My composition starts with a simple phrase, symbolizing an idea or memory, as it travels through the neurons and synapses. The phrase repeats three times, each time getting louder and stronger.

The student continued by explaining how the ideas being conveyed change as the notes become shorter:

Then part B is a fast series of notes that symbolize Long Term Potentiation, or the chemical process the memory goes through in order to solidify and become a long-term memory.

The other two factual content elements—Scientific Story and Scientific Topic—were much less common than Conveying Information (Figure 1). Scientific Story was most commonly represented via Lyrics (Table 3). Interestingly, Scientific Topic had significant representation by all four musical elements: Genre (6%), Lyrics (6%), Instruments (9%), and Structure (12%). In an example of the latter, a student used the soothing structure of a melody to convey the soothing effects of a pill: ‘The song is … very soft yet subtle. It’s very melodic and easy to listen to like rain or snow. While playing the song I picture the pill working its way through the body cleansing as it goes and the salve eating away all the impurities.’
Emotional impact

Students made Science–Music connections that went well beyond the factual (Figure 1). Among the connections to Affect or Personal Story, the most frequent connection was Affect–Structure (26%). Many of the Affect–Structure connections included the use of major and minor keys to convey happy and sad moods, or the use of fast and slow tempos to convey anxiety/excitement and calmness, respectively. Other uses of Structure were more unusual. For example, a student who completed a project about dreams tried to make listeners fall asleep by experimenting with the time signature, tempo, and chords (all of which were considered structural aspects of music). In another example, a student wrote a song about congenital amusia, a condition in which, in extreme cases, listeners perceive normal music as being harsh and unpleasant. The student’s song gradually becomes cacophonous to replicate what someone with congenital amusia might experience, e.g. ‘In the fourth level, the flute plays “in-sync” with the slide whistle and ocarina, which plays purposely out of tune. The Clarinet squeaks so much, that it begins to resemble somebody smashing pots and pans.’ Thus, the song’s musical structure simulates the sensations of someone with congenital amusia.

Many of the emotional impacts that students tried to convey did not fit into any of the musical categories that we defined. In 27% of the statements—an even higher prevalence than that of Structure–Affect—students indicated that they were trying to elicit an emotional response, but they did not specify how their music did so. For example, a pair of students discussed the affective response of their composition about genetics in general terms:

Our song is meant to be affective both by being unique and individualistic. We feel that merely writing a paper would do genetics an injustice. For genetics are so creatively expressed through our physical aspects and our hereditary characteristics, a musical composition would be a phenomenal way of expressing such emotion.
The emotional impact of the songs also communicated personal stories about the science. Students usually did this with their Lyrics (Personal Story-Lyrics, 21%). For example, a student talked about her mother’s cancer:

The song I wrote conveys images and emotions I pictured in my head about my mom while she was fighting the disease. It portrays how I thought my mom felt during her struggles during treatments, appointments, and surgeries. The words I chose are there to allow people and myself, to see how someone fighting this disease might feel. Some may feel lost and confused, while others find strength to battle against their diagnosis.

**RQ2: to what extent can songwriting help students create practice-linked scientific identities?**

As noted above in the section Engagement: Development of Practice-Linked Scientific Identities, Nasir and Hand (2008) identify four key contributors to practice-linked identities: (1) access to the content domain, (2) personal identification with that domain, (3) opportunity to take on roles integral to the practice, and (4) opportunity for self-expression. To what extent do Expo music projects fulfil these criteria?

Criterion (1) is probably fulfilled through students’ classroom teachers, their assigned Expo mentors, and/or—for students working in groups—their fellow group members. Furthermore, the very nature of the Expo music projects covers criterion (4), in that composing music is an opportunity for self-expression. Therefore, we looked for evidence of criteria (2) and (3) in students’ artist statements.

We considered criterion (2) in terms of students’ personal identification with the domains of both music and science. Specifically, we used artist statements to infer why students chose the music category of the Expo over the other available categories, and why they chose the specific scientific topics that they did.

65% of students used their artist statements to explain or imply why they chose the music category of the Expo. Within this sample, we noticed two general categories of reasons: previous experience creating music (Music Experience), and/or being a fan of music (Music Fan). About half of the students explicitly indicated that the Expo was an opportunity to take advantage of their existing musical skills and interests. As one student wrote,

I love rhyming and making up silly raps so I thought that this would be a good opportunity to practice and express my love for rapping, entertaining, and rhyming because I can talk about my topic … through a rap.

Other students found inspiration in the example of professional musicians whom they admired. For example, one group sought to follow the lead of Snoop Dogg, Jay-Z, Big Gipp, and Elton John. ‘Through their sacrifices and interpretations of music, these cutting edge artists have made it possible for us to understand things we may never have been able to,’ a member of this group wrote. ‘These artists all stand for freedom and independence; and they portray their true emotion through their music. We hope to portray all of our emotion and feelings about genetics when going to record our music.’

62% of the students explained or implied why they chose their scientific topic (Figure 2). The most common reasons involved first-hand personal experiences with the topic (Firsthand Experience)—often an ailment—or the experiences of acquaintances (Know Someone). These reasons constituted 17 and 20%, respectively, of all students. For example, one student wrote a song about cirrhosis because he suffered from the disease, hoped to learn more about it, and wanted to explore its emotional effects. Several students wrote songs in honour of family members who suffered from illnesses such as cancer. For example, a student wrote, ‘When [partner’s name] and I were thinking about what music we should come up with and play, we never turned our thoughts away from our grandmothers,’ both of whom had died of cancer. Other participants (14%) found inspiration through societal concerns. For example, ‘The bird flu seems to have flood[ed] the new[s] lately. Because of this I found it utterly imperative to grasp the anatomy of this killer.’
Finally, to assess whether Expo songwriting projects enabled students to take on roles integral to science practices (Nasir & Hand criterion 3), we searched the artist statements for evidence of the eight key NGSS Science and Engineering Practices. As shown in Table 6, all music projects were considered to involve NGSS Practice 8: obtaining, evaluating, and communicating scientific information. 42% of artist statements also included evidence of Practice 2, working with models—generally musical analogies for scientific ideas. For example, a student described the opening of an instrumental song about genetic mutations:

Then I introduced the chordal structure of my piece: a simple and logical progression representing the perfect and organized DNA sequence of the cell during interphase. The bright, joyous melody shows the success of the cell’s processes during its normal life cycle. A countermelody is added, symbolizing the beginning of DNA replication in the cell. The perfect fifths and thirds show that the proper complementary base pairs are being built from the old strand. However, occasional embellishments and added notes represent the minor, non-harmful mutations that may occur during DNA’s replication process.

Other NGSS Practices that showed up somewhat frequently in artist statements were constructing explanations (Practice 6; 22% of statements) and asking questions (Practice 1; 12% of statements). Practices 3, 4, 5, and 7 were evident in less than 5% of the artist statements (Table 6).

Discussion

Both Writing To Learn (WTL) and content-rich STEM music are said to offer benefits relating both to discipline-specific content and to student engagement (Balgopal & Wallace, 2009; Crowther, 2012; Governor et al., 2013; Reynolds et al., 2012). Here we return to the question of the extent to which these benefits are evident in ‘Songwriting To Learn’ projects of high school science fair students.

RQ1: how do students’ musical compositions represent STEM content?

Expo students made numerous creative and varied connections between scientific elements and musical elements. These connections are unique to each project and constitute evidence of
constructionist learning. That is, students constructed their understanding of scientific topics in part by constructing songs in which scientific elements were mapped onto musical elements.

A key result is that Expo students did far more than present facts in lyrics (Convey Information-Lyrics). Students used lyrics to present a scientific topic, convey affect, tell a personal story, and communicate a scientific story, in addition to using them to conveying information. Students also made frequent use of musical elements other than lyrics—Structure, Instruments, and Genre—to represent scientific elements (Figure 1). Finally, 35% of the students’ compositions were instrumental pieces without words. These data collectively suggest that high school students can, with creativity and sophistication, harness aspects of music that are generally ignored by instructors, who focus almost exclusively on song lyrics as a means of content delivery (Governor et al., 2013; Maute, 1987; Smolinski, 2011). Thus, open-ended songwriting exercises may provide alternative routes by which students can process and communicate STEM content (Crowther et al., 2017).

RQ2: to what extent can songwriting help students create practice-linked scientific identities?

Overall, the student songwriters appeared to be making their way toward practice-linked scientific identities, as judged by Nasir and Hand’s (2008) four key criteria. The format of the Expo essentially ensured fulfilment of criteria 1 (access to the scientific content domain) and 4 (self-expression within this domain). Beyond that, song-writing students had personal connections to the domain of science that fell short of personal identification with this domain (criterion 2), and had some modest opportunities to take on roles integral to scientific practices (criterion 3).

Students’ comments on why they chose the music category and why they chose their particular scientific topics suggest that their musical identities run deep, whereas their scientific identities are still emerging. Most students who chose the music category in the Expo indicated that they were attracted to this category because they had assumed a musical identity before, as a musician and/or as a music fan. In contrast, students usually did not justify their choice of a scientific topic by alluding to scientific identity; for example, few (11%) described topics as inherently interesting, and none described them as likely targets of their future professional work (Figure 2). Instead, they emphasized their topics’ connections to other aspects of their identity, such as their friends and family. Forming a personal connection to science does represent one step along the way of developing a scientific identity (Bereiter, 1995; Clegg & Kolodner, 2014) and thus partially fulfils criterion 2 (personal identification with the domain of science). The open-ended nature of the Expo projects enabled this partial fulfilment, as it allowed students to choose specific topics to which they had a personal connection.

It is unsurprising that the student songwriting projects only involved a few NGSS-recommended Science and Engineering Practices (Table 6) and thus incompletely fulfilled criterion 3 (integral roles in scientific practices). Nevertheless, the current Expo instructions to students (Appendix 1) could be modified to ask students to discuss how musical models of science are similar to and differ from other types of scientific modelling. Also, if scientific practices are indeed a pedagogical priority, music-related assignments could be adjusted to incorporate more of these practices. One student explored music therapy by analysing the physical reactions of his Alzheimer’s disease-stricken grandfather to songs; thus, student-created songs can themselves be a basis for data collection and analysis. Furthermore, students could potentially focus their research and songwriting on specific peer-reviewed scientific studies, another way of going beyond science facts to learn more about the process of science (Thanukos, Scotchmoor, Caldwell, & Lindberg, 2010).

Limitations and applications

Our focus on students’ artist statements is both a strength and a limitation of the current study. By limiting ourselves to this component of the students’ music projects, we were able to access...
considerable archival data and analyse the work of over 90 students in some detail. However, the high variability among the artist statements, students’ limitations in self-reporting (Gonyea, 2005), and our inability to investigate other aspects of the projects resulted in an incomplete look at what students gained from their projects. For instance, we cannot be sure that the ‘Song-writing To Learn’ studied here is a full-fledged form of Writing To Learn, as the artist statements themselves did not necessarily reveal such critical WTL components as sequential reasoning and metacognition (Fry & Villagomez, 2012; Reynolds et al., 2012). Listening to the students’ music could have helped us verify the themes identified in the artist statements, or even identify additional themes. Interviewing participants could have given us deeper insight into their prior level of interest in and experiences with science and music, how they experienced using music to explore a science topic, and how participating in the Expo affected their subsequent interest in and identification with science and music. Thus, overall, our use of archived materials significantly restricted the sorts of research questions we could ask and answer. We see our work as a good jumping-off point for prospective studies in which interventions are studied in real time, rather than retrospectively.

Our findings are most applicable to situations that resemble the Expo in providing open-ended, sustained opportunities for students to explore scientific topics. Such opportunities are relatively rare, however. The challenge for instructors is to create these opportunities in formal or informal learning environments with students who may be less interested in science than typical Expo participants. Future work could explore whether and under what conditions broader groups of students with more heterogeneous abilities and levels of motivation—both scientifically and musically—would find success investigating science topics through music.

**Conclusion**

Science education traditionally presents science in a way that is disconnected from lived experience. However, tools such as music may bridge this gap by helping students form personal connections to science. In the current study, we analysed artist statements accompanying music compositions that high school science fair participants created to explore their chosen science topic. Students’ music projects connected scientific elements and musical elements in numerous unusual ways, consistent with the constructionist paradigm of learning (RQ1). These projects included personal connections to specific topics and occasional performance of authentic science and engineering practices, perhaps moving students toward practice-linked scientific identities (RQ2). We conclude that the Student Bio Expo gave students a unique opportunity to draw on their practice-linked identities in one domain (music) to express their growing understanding in another domain (science). Thus, this study shows how students’ non-science interests (here, music) may be leveraged to support their engagement in science. Interest in music may hold exceptional educational power due both to its widespread resonance with young people and the many components (genre, instruments, lyrics, structure) that lend themselves to the expression of scientific information, as demonstrated here.

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No potential conflict of interest was reported by the authors.
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