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Leveraging the power of music to improve science education

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ABSTRACT

We assessed the impact of music videos with science-based lyrics on content knowledge and attitudes in a three-part experimental research study of over 1000 participants (mostly K-12 students). In Study A, 13 of 15 music videos were followed by statistically significant improvements on questions about material covered in the videos, while performance on 'bonus questions' not covered by the videos did not improve. Video-specific improvement was observed in both basic knowledge and genuine comprehension (levels 1 and 2 of Bloom's taxonomy, respectively) and after both lyrics-only and visually rich versions of some videos. In Study B, musical versions of additional science videos were not superior to non-musical ones in their immediate impact on content knowledge, though musical versions were significantly more enjoyable. In Study C, a non-musical video on fossils elicited greater immediate test improvement than the musical version ('Fossil Rock Anthem'); however, viewers of the music video enjoyed a modest advantage on a delayed post-test administered 28 days later. Music video viewers more frequently rated their video as 'fun', and seemed more likely to revisit and/or share the video. Our findings contribute to a broader dialogue on promising new pedagogical strategies in science education.

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Educational music; content-rich music; online instruction

Introduction

The provision of high-quality Science, Technology, Engineering, and Mathematics (STEM) education is critical in today's complex, information-based, technology-dense world. The number of STEM-based jobs around the world continues to grow vigorously. For the period 1995–2007, the number of science and engineering research positions increased by ~40% in the USA and the European Union and by over 100% in countries such as China and South Korea (National Science Foundation, 2012). The World Economic Forum has included scientific innovation and the availability of scientists and engineers as one of its key pillars of global competitiveness (Schwab, 2012). Meanwhile, STEM literacy remains vital in allowing nonscientist citizens to set cultural, economic, and political priorities relating to science: what areas are most deserving of additional research, how the government should regulate new technologies, and so on (Feinstein, 2011).

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Worldwide, educational institutions are struggling to produce STEM-savvy graduates (Dekkers & De Laeter, 2001; Read, 2010). In the USA, though the number of credits in mathematics and science earned by high school graduates continues to increase (National Science Foundation, 2012), these students are not performing particularly well in STEM subjects. Results from the 2009 National Assessment of Educational Progress (NAEP) showed that relatively few students in grades 4, 8, and 12 reached their grade-specific proficiency levels in science (National Science Foundation, 2012). Another cause for concern is students' lack of interest in science topics; only 12% of American high school students who took the ACT college readiness exam expressed interest in a STEM major or occupation (ACT, 2013). Finally, the often-large gaps between the views of professional scientists and those of the general public (Funk et al., 2015) suggest that the public's science literacy leaves something to be desired.

The current status quo in STEM education suggests considerable room for improvement. The purpose of this paper is to report on a three-part empirical study of music's ability to enhance students' understanding of and interest in science concepts. The findings contribute to a broader dialogue on promising new pedagogical strategies in science education.

Background and Context

The Current State of K-12 Science Education

Students' science achievement is directly related to the quality of instruction they receive (Johnson, Kahle, & Fargo, 2007; Rivkin, Hanushek, & Kain, 2005). In particular, students are more likely to succeed in science when they have access to teachers with strong content knowledge and pedagogical knowledge (Croninger, Rice, Rathbun, & Nishio, 2007; Goldhaber & Brewer, 1997, 1998). Unfortunately, this is not the case for many students in the USA and elsewhere (Kriek & Grayson, 2009; National Research Council, 2007; Panizzon, Westwell, & Elliott, 2010; Shen, Gerard, & Bowyer, 2010).

School reform efforts may unwittingly impede progress in science education. (In the locations of the present study, these have included the 2001 No Child Left Behind Act in the USA and the 2010 implementation of National Standards for Years 1 to 8 in New Zealand.) Such efforts typically hold schools responsible for improving their students' performance in English Language Arts (ELA) and math. As a result, instructional time tends to shift away from other, lower-stakes subjects (Diamond & Spillane, 2004; Marx & Harris, 2006; McMurrer, 2008). In the USA, there is evidence to suggest that this shift has had a deleterious effect on students' science achievement (Maltese & Hockhbein, 2012; Marx & Harris, 2006).

Best Practices in K-12 Science Education

Even if school reform initiatives placed equal weight on science as they do on reading and math, empirical evidence suggests that instruction geared toward passing standardized tests may not promote students' understanding of scientific concepts. The US National Research Council (2007) recommends using a broad range of instructional strategies that develop students' understanding of scientific concepts and how they are related

and provide them with opportunities to learn and use the discourses of science. Nurturing students' motivation, engagement, and identities in science is also important (National Research Council, 2009).

Similarly, Donovan and Bransford (2005) list key elements for effective science education as (1) drawing on students' prior knowledge and interests; (2) encouraging students to exercise their powers of observation, imagination, and reasoning; and (3) providing students with opportunities to think metacognitively about their learning processes through inquiry-based activities. Unfortunately, these elements are often missing in K-12 science classes (Kesidou & Roseman, 2002).

The elements identified by Donovan and Bransford (2005) represent alternative science teaching strategies that stand in stark contrast to traditional methods involving a teacher dispensing knowledge to students from a textbook at the front of the classroom. In an early meta-analysis that compared these teaching strategies, Wise and Okey (1983) found that all 12 of the alternative strategies were more effective at improving students' science achievement than traditional strategies. In a follow-up study looking at middle and high school science teaching, Wise (1996) found that the alternative teaching strategy with the greatest effect size involved the use of instructional media. This finding aligns with the results of Schroeder, Scott, Tolson, Huang, and Lee's (2007) meta-analysis, which identified the use of instructional technologies, including video, as one of the eight principles for effective science teaching. Subsequent research has found that science activities that are hands-on in nature and allow for engagement with technology elicit higher interest among students (Swarat, Ortony, & Revelle, 2012).

The Role of Music in Science Education

The above discussion points to pedagogical approaches to science education that are personally relevant and provide multiple modes of entry. Music meets both of these criteria. With respect to personal relevance, the central role that music plays in youth's sense of identity, belonging, and culture is well documented (Bennett, 1999, 2000). Different music genres are typically associated with distinct clothing styles, speech, and mannerisms, all of which serve as markers of identity and group affiliation (Arnett, 1996; Brake, 1985). In addition to shaping their externally oriented identities, youth use the emotions and sentiments expressed in songs to explore their inner feelings and values.

Recognizing the power of music in young people's lives, some educators have used music to enhance students' engagement in school. For instance, music was used in an undergraduate sociology course to help students make a personal connection both to the instructor and to the course content (Albers & Bach, 2003). At the high school level, teachers in one Chicago high school used hip-hop culture and music to make the social studies curriculum more engaging and personally relevant to their African American and Latina/o students (Stovall, 2006). Hip-hop culture and music has also been used to connect science to urban youth's cultural background, thereby decreasing their feelings of personal alienation from the discourses and practices surrounding science education (Emdin, 2010).

In addition to providing opportunities for personal connection to science, music offers a new entry point into science concepts and discourses. Gardner's (1983, 1999) theory of multiple intelligences (MI theory) is widely recognized as providing the theoretical

justification for using multiple entry points into a particular subject. According to MI theory, individuals do not possess a single, general intelligence but rather eight or more relatively autonomous intelligences. Every individual possesses a distinct profile of intelligences, and people may demonstrate aptitude in certain intelligences but not others. Due to students' diverse intelligence profiles and aptitudes, Gardner (2006) argues that teachers should provide them with a variety of entry points into key topics, concepts, or ideas. By drawing on different intelligences, these diverse entry points increase the likelihood that each student will be able to draw on a cognitive strength to access a particular topic. Such pluralization also supports deep understanding, since looking at a topic or concept from a variety of angles is likely to enhance one's understanding of it. With respect to musical intelligence in particular, Gardner (2006) has described how music can be used as an entry point to teach students about topics as diverse as evolution, the Holocaust, and art history. In support of this view, graduates of a fifth-grade 'Performing History' program (in which they reenacted historical events in the format of musical theatre) did better on a sixth-grade history test than their peers (Otten, Stigler, Woodward, & Staley, 2004).

Using music as an additional mode of entry may also aid students' memory (Crowther, Williamson, Buckland, & Cunningham, 2013), though not all scholars agree that music is an efficient enhancer of recall (Schulkind, 2009). Research showing that memories are stronger when they are encoded in an emotional state suggests that the emotional charge of music could enhance students' ability to remember academic content (Tesoriero & Rickard, 2012). More generally, music can modulate students' arousal in academic settings; students who are neither over-stressed nor overly sedate may be best positioned to retain content (Crnec, Wilson, & Prior, 2006; Schellenberg, Nakata, Hunter, & Tamoto, 2007). In addition, there is evidence that the repetition involved in music aids in the memorization of facts (Calvert & Tart, 1993; Cirigliano, 2013). Mnemonic devices like songs are used to provide musical scaffolds into which non-musical information can be placed (Thaut, Peterson, McIntosh, & Hoemberg, 2014). Finally, songs' rhythms and rhyme schemes facilitate recall of song lyrics by strongly restricting the possible words of those lyrics (Bower & Bolton, 1969).

Though both theory and research support the use of music to teach science concepts, few empirical investigations have systematically explored music's impact on academic performance beyond the primary grades (Crowther, 2012). One unusually thorough multi-classroom study (Governor, Hall, & Jackson, 2013) found evidence to suggest that science music does not merely function as a mnemonic device but also has the potential to help middle school students build deep understanding of scientific concepts. However, this study did not attempt to compare learning outcomes in music-exposed and non-exposed students. In studies where such comparisons have been made, musical enhancements of STEM knowledge have, with rare exceptions (Lesser et al., 2014), been reported only in certain subgroups (McCurdy, Schmiede, & Winter, 2008), a single course (Van-Voorhis, 2002), and/or a single song (Lemieux, Fisher, & Pratto, 2008; Smolinski, 2011). To determine whether effects of STEM-based music can be seen more broadly, we undertook a multi-part study involving 16 songs and over 1000 participants. Our study thus achieved much broader sampling than any previous study in this area, with the corresponding limitations that we could not exhaustively analyze any particular song or participant group, and could not always avoid selection bias.

Study A: Music Videos at Science Outreach Events

Methods

Research Question

The primary research question posed by Study A was: to what extent does watching content-rich music videos increase learners' understanding of science concepts?

Choice of Videos

The videos included in this study (listed in the Appendix) were chosen because they (a) were considered musically appealing, (b) included STEM content suitable for a multiple-choice test, and (c) were publicly accessible via YouTube. A majority of the songs and videos were created by professional educators (classroom instructors, graduate students, and educational consultants); the rest were created by professional musicians. Although much is now known about how videos may be designed to maximize learning (Guo, Kim, & Rubin, 2014; Mayer, 2008), we chose to study online videos typical of those freely available to teachers and students, rather than restricting ourselves to those judged ideal for learning.

Study Sites

Study A was one component of five science- and STEM-themed outreach events (organized by others) in Washington state (USA) in the spring of 2013 (see Table S1 in Supplementary Material). The scope and audience of these outreach events varied considerably; most targeted K-12 students or a subset thereof, but some also encouraged attendance by the general public.

Protocol

Visitors to our table were greeted with a brief statement that we are interested in whether people can learn science through music, and that this table is a chance for people to explore whether music is helpful to them. Interested visitors then sat down at an open computer (4–5 laptops with headphones were used at each event). From the Quizzes page of the Sing About Science website (www.singaboutscience.org), they selected one of the listed music videos according to their age and interests. Clicking on the title of a video launched a pre-video test in a new browser tab. This test included four video-related questions and one 'bonus question' not covered by the video, and additional questions about participants' age, sex, and confidence in their answers (choices: very high, high, medium, low, and very low). Participants clicked the CONTINUE button to view the selected video. (participants who selected 'The Double Life of Amphibians,' 'Meet the Elements', or 'Shake' were shown a lyrics-only video or a 'visually rich' video according to a randomization function embedded in the pre-video test page.) Clicking CONTINUE again led to the post-video test, which included the same content and confidence questions as the pre-video test, plus an additional question on what participants thought of the video (choices: I love it, I like it, It's OK, I dislike it, I hate it). Participants clicked a FINISH button to see a final screen comparing the correct answers to their own answers. The whole process took an average of nine minutes per participant.

Participants and Attrition

A total of 568 complete datasets (defined as including both pre- and post-test responses) were collected at the five outreach events (Table S1). These 568 datasets correspond to approximately 550 people; a very small fraction of visitors watched more than one video. Participation was nearly equal among males ($N = 278$) and females ($N = 260$; sex was not specified in 30 cases). Among 543 reported ages, 6% were 7 or younger, 54% were 8–12, 24% were 13–17, 4% were 18–22, and 12% were 23 or older.

Midway through the second event, we began quantifying the activity completion rate among those who started our activity. This rate was 53% until we made an improvement to the website interface during the third event. After changing the website so that clicking on a song title opened a new browser tab rather than a whole new window, the completion rate rose to 72%. This completion rate is satisfactory in light of the many possible causes of attrition (e.g. encouragement to leave by friends or chaperones, temporary Internet connectivity problems, boredom, confusion about the interface).

Classification of Test Questions According to Bloom's Taxonomy

Bloom's taxonomy of cognitive domains (Bloom, 1956) has previously been applied to biology exam questions (Crowe, Dirks, & Wenderoth, 2008); questions can be classified according to the highest Bloom level required in answering them. In the present study, two science educators otherwise unconnected with the study, but trained by a coauthor of the 'Biology in Bloom' article (Crowe et al., 2008), classified each test question in this way.

Data Analysis

Participants' answers on the 'very low'-to-'very high' scale and the 'I hated it'-to-'I loved it' scale were converted to 0-to-4 scales for easier analysis. *T*-tests were performed as noted below. For comparisons of pre- and post-test scores, *t*-tests were 1-tailed, reflecting the hypothesis that scores would improve following the videos. Holm's sequentially rejective Bonferroni method was used to adjust the level of statistical significance for multiple comparisons such that the overall probability of a Type I error would be ≤ 0.05 (Shaffer, 1995).

Results

Science Music Videos Can Improve Scores on Science Tests

Test-by-test data are summarized in Table 1. Visual inspection of the data suggests that performance on the video-related questions improved following many of the videos, whereas performance on the unrelated ('bonus') questions generally did not improve. Gains in test performance were statistically significant for 13 of the 15 videos, covering many distinct scientific topics in many different musical styles (see Table 1 for details). With each of the four video-related questions being worth 1 point, the mean pre-video score across all tests was 1.72 and the mean post-video score was 2.49, for a mean gain of 0.77 points. If we ignore the 124 datasets where the entire video was not watched (according to time stamps) and/or where a perfect pre-video score precluded improvement, this mean gain rises to 1.02 points.

Given this overall trend toward improved test scores following the videos, we asked whether improvements were linked to possible covariates such as event, age, and sex.

Table 1. Summary of the science music video data (Study A)

Music video topic	# of subjects	Median age	Related questions (pre → post)	Unrelated question (pre → post)	Enjoyed video? (0–4 scale)
Amphibians (lyrics only)	52	9	1.87 → 3.10 ^a ($p < .0001$)	0.15 → 0.15	2.6
Amphibians (visually rich)	46	9	1.90 → 2.92 ^a ($p < .0001$)	0.18 → 0.33	2.8
Elements (lyrics only)	37	9	1.32 → 2.22 ^a ($p = .002$)	0.22 → 0.22	3.1
Elements (visually rich)	32	9	1.50 → 2.09 ^a ($p = .01$)	0.25 → 0.28	3.2
Matter (lyrics only)	31	9	1.61 → 2.19 ^a ($p = .01$)	0.16 → 0.19	2.8
Matter (visually rich)	30	10	2.13 → 2.20($p = .36$)	0.17 → 0.13	2.5
Five senses	42	11	2.40 → 2.36($p = .41$)	0.52 → 0.52	2.6
Fossils	69	12	2.32 → 2.97 ^a ($p < .0001$)	0.59 → 0.55	3.2
Nervous system	62	13	1.77 → 2.29 ^a ($p = 0.0008$)	0.21 → 0.27	3.0
Wheat agriculture	35	13	0.77 → 1.74 ^a ($p = 0.0006$)	0.26 → 0.40	2.7
Viruses	41	15	1.20 → 2.10 ^a ($p < .0001$)	0.32 → 0.20	2.7
Brain	41	17	1.98 → 2.71 ^a ($p = .001$)	0.27 → 0.27	3.3
Geometry	16	17	1.06 → 3.19 ^a ($p < .0001$)	0.00 → 0.00	2.5
Chemical ecology	12	35	0.58 → 3.50 ^a ($p < 0.0001$)	0.08 → 0.25	3.1
Muscle glycolysis	22	39	1.14 → 1.64 ^a ($p = 0.009$)	0.14 → 0.09	2.5
Overall	568	12	1.72 → 2.49	0.30 → 0.29	2.9

^aStatistically significant improvement according to a paired 1-tailed t -test corrected for multiple comparisons (p values shown in parentheses).

Scores improved significantly at four of the five outreach events (the exception being an event with only 11 participants; data not shown) and across all age groups (Figure 1). Similarly, pre- to post-video improvement was of the same magnitude for females and males, though males were significantly more confident in their answers both before and after the videos (Figure 2). Thus, the post-video improvement was robust in the sense of being observed for both sexes and for multiple events and age groups.

Lyrics-only videos are at least as beneficial to test performance as visually rich videos. Some of the music videos we originally selected for this study displayed few or none of

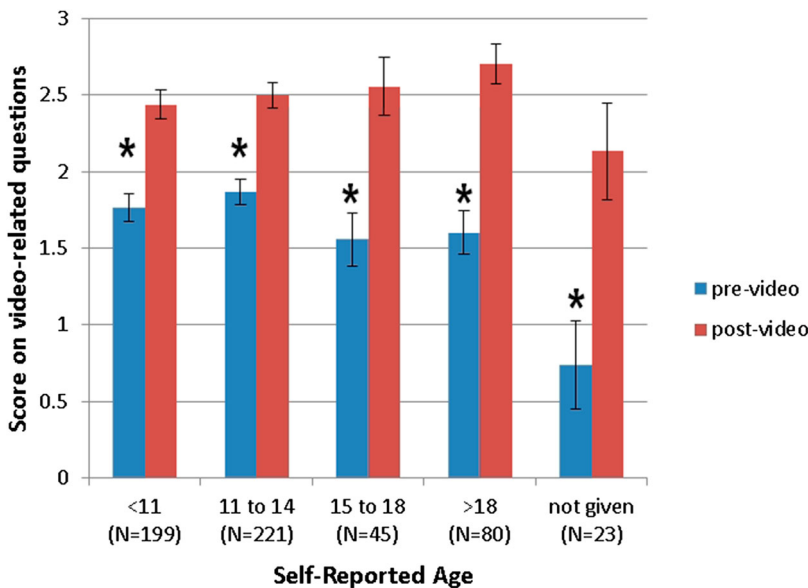


Figure 1. (Colour online) Pre- and post-video test scores by age group (Study A). Values shown are means $\pm$ standard errors. All pre-test to post-test improvements were statistically significant (paired t -tests, $p < .001$ for each)

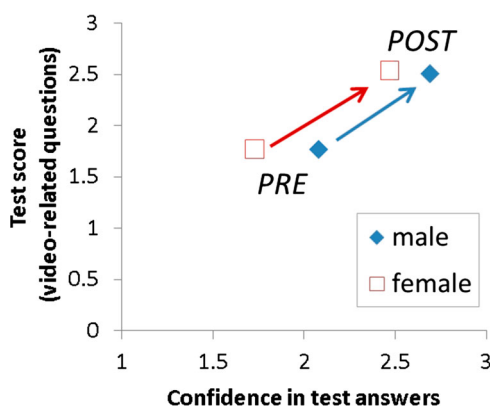


Figure 2. (Colour online) A comparison of test performance and confidence of males and females (Study A). Arrows show changes from pre-video to post-video values. Both males and females significantly improved their test scores (paired t -tests, $p < .001$ for each). Average scores for males and females were not significantly different on either the pre-test or the post-test (two-sample t -tests, $p > .8$ for each), but males were significantly more confident in their answers both before (two-sample t -test, $p = .0001$) and after watching the videos (two-sample t -test, $p = .004$)

the songs' lyrics, but extensive and engaging animations or live-action footage; we refer to these videos as 'visually rich' videos. To investigate the possible importance of the videos' visuals, some participants were randomly directed to alternative versions of 'The Double Life of Amphibians', 'Meet the Elements', or 'Shake'. These alternative versions included the same music, but their visuals consisted solely of on-screen lyrics, displayed 1–4 lines at a time. There was a non-significant trend toward greater test score improvement for the lyrics-only videos as compared to the corresponding visually rich videos (Table 1). Thus, for boosting test scores, the lyrics-only versions are not inferior to the visually rich versions, at least when viewed a single time.

Post-video Improvement Reflects Genuine Comprehension

Music is sometimes considered an educational tool that is useful only for fostering rote memorization. To determine whether music can improve understanding that goes beyond recall of lyrics per se, each test question was classified according to Bloom's taxonomy, and per-question improvements on 'knowledge' questions (the lowest Bloom level) were compared with per-question improvements on 'comprehension' questions (the next-lowest Bloom level) for each test (Table 2; see Supplementary Material for question-by-question classifications). Each set of values (the middle and right columns of Table 2, respectively) was then compared to a hypothesized mean change of 0 in a 1-sample t -test and found to be significantly greater than 0 ($p \leq .001$ for each). In other words, post-video test performance improved significantly on the more complex 'comprehension' questions as well as the straightforward 'knowledge' questions.

Enjoyment of Videos

'I like it' (3 out of 4 points on the enjoyment scale; see Table 1) was the average response to most of the videos tested. This is not surprising, since our subjects were volunteers who chose to undertake our activity amidst other competing opportunities.

Table 2. Improvements on 'knowledge' and 'comprehension' questions (Study A)

Music video topic	Per-question improvement by Bloom level	
	Knowledge	Comprehension
Amphibians (lyrics only)	0.26	0.36
Amphibians (visually rich)	0.24	0.27
Elements (lyrics only)	0.22	N/A [#]
Elements (visually rich)	0.15	N/A [#]
Matter (lyrics only)	0.18	0.11
Matter (visually rich)	−0.02	0.05
Five senses	−0.04	0.07
Fossils	0.14	0.19
Nervous system	0.12	0.14
Wheat agriculture	0.29	0.11
Viruses	0.24	0.17
Brain	0.38	−0.01
Geometry	0.54	0.50
Chemical ecology	0.75	0.71
Muscle glycolysis	0.05	0.15
Average	0.24**	0.22*

*Significantly greater than 0 according to a 1-tailed 1-sample *t*-test ($df = 12$, $t = 3.909$, $p = .001$).

**Significantly greater than 0 according to a 1-tailed 1-sample *t*-test ($df = 14$, $t = 4.528$, $p = .0002$).

[#]No test questions about 'Meet the Elements' were rated as comprehension level.

Results Summary

Overall, 13 of the 15 science music videos led to statistically significant gains in student test performance. These gains were found across all age groups and for both male and female students. Moreover, students improved their scores on the more complex 'comprehension' questions as well as the straight 'knowledge' questions. Scores on the unrelated 'bonus' questions did not show any change, suggesting that the gains were attributable to watching the science music video rather than simply the repetition of the question. It is noteworthy that participants achieved these gains even though their classroom teachers were generally elsewhere and their performances on our tests had no effect on their grades. That is, participants learned from the music videos despite an absence of the usual extrinsic incentives to pay attention.

Study B: Comparison of Musical and Non-musical Videos

Methods

Research Question

Limitations of Study A included the lack of a comparison between music videos and non-musical versions. Thus, Study B asked whether the musical component of these videos is critical for learning—that is, whether people learn more from musical versions than from non-musical versions.

Preparation of Videos

The lead author identified content-rich songs with repeated choruses that might lend themselves to rapid uptake of information. He then created simple videos combining his own newly recorded spoken introductions with song excerpts previously recorded by others, and parallel videos of similar length in which the song excerpts were replaced with (newly recorded) spoken information. All spoken and sung words were displayed as

part of each video. Three of the four videos also included a single illustrative figure. Thus the visuals of the videos were quite simple, consisting almost entirely of the text being spoken or sung.

Study Sites

Like Study A, Study B drew participants from larger science/STEM outreach events, which in the case of Study B included the STEM building at the Central Washington Fair (Yakima, WA, USA, 20 September 2013), Life Sciences Research Weekend (Pacific Science Center, 1–3 November 2013), and Paws-On Science (Pacific Science Center, 5–6 April 2014). Study B also recruited subjects from the classrooms of Totem Middle School (Kent, WA, USA) and Glacier Peak High School (Snohomish, WA, USA).

Protocol

Study B's protocol was identical to Study A's protocol, with three exceptions. First, there was no pre-video test. Second, participants were randomly assigned by the web browser to one of four sequences: musical science video+test (music, immediate); musical science video+distractor video+test (music, not immediate); non-musical video+test (no music, immediate); or non-musical video+distractor video+test (no music, not immediate). All distractor videos were of age-appropriate math songs. Third, aside from being asked whether they enjoyed the science video, participants were also asked, 'If you had the chance, would you learn about other science topics by watching videos similar to the one you saw?' (Choices: 'definitely', 'yes', 'maybe', 'no', and 'definitely not').

Participants

A total of 403 complete datasets were collected at the five study sites. Reported genders were nearly equally split between males ($N = 187$) and females ($N = 179$). Among reported ages, 4% were 7 or younger, 42% were 8–12, 39% were 13–17, 2% were 18–22, and 12% were 23 or older.

Data Analysis

Possible effects of music and immediacy (whether a distractor video was seen) on post-video test performance were subjected to ANOVA using the following linear model:

$$\text{test score} = \beta_0 + \beta_1 \cdot (\text{music}) + \beta_2 \cdot (\text{test immediacy}) + \beta_3 \cdot (\text{music}) \cdot (\text{test immediacy}) + \varepsilon,$$

where 'music' and 'test immediacy' are binary variables (0 or 1) and ε is an error term. As before, participants' answers on the 'I hated it'-to-'I loved it' and 'definitely not'-to-'definitely' scales were converted to 0-to-4 scales for easier analysis. Responses to musical and non-musical videos were compared with 2-sample, unequal-variance, 1-tailed t -tests, with the 1 tail reflecting a hypothesis that musical videos would be preferred. Holm-Bonferroni corrections for multiple comparisons were applied as in Study A.

Table 3. Test performance and participant feedback after musical and non-musical videos (Study B)

Video topic	# of subjects	Median age	Immediate test musical vs. non-musical	Delayed test musical vs. non-musical	Enjoyed video? (0–4) musical vs. non-musical	Learn via similar videos? (0–4) musical vs. non-musical
Simple machines	110	9	3.18 vs. 2.94	2.95 vs. 3.42	2.71 vs. 2.20* ($p = .003$)	2.70 vs. 2.20* ($p = 0.009$)
Cells	152	12	1.49 vs. 1.58	1.19 vs. 1.54	2.16 vs. 1.75* ($p = .006$)	2.14 vs. 1.71* ($p = .009$)
Batteries	87	15	1.48 vs. 1.50	1.50 vs. 1.40	2.43 vs. 1.90* ($p = .005$)	2.30 vs. 2.08
Muscle Contraction	54	37	1.71 vs. 2.09	1.25 vs. 1.18	2.54 vs. 2.28	2.71 vs. 2.32

Note: Maximum test score was 6 for simple machines, 3 for cells, 4 for batteries, and 3 for muscle contraction.

*Statistically significant differences according to 2-sample t -tests corrected for multiple comparisons (p values in parentheses).

Results

Test scores were similar after musical and non-musical videos, with or without intervening 'distractor videos'. We hypothesized that, when students are presented with the same information multiple times, they are more attentive and absorb the information more readily when it is presented in a musical format. Furthermore, we hypothesized that musically presented information might be more memorable and thus be retained better during a distracting task (watching an unrelated video). However, neither hypothesis was supported by our data (Table 3). ANOVA revealed no statistically significant interaction between music and test immediacy (see above); moreover, neither the main effect of music nor the main effect of test immediacy was significantly different from 0 (see Supplementary Materials for statistical details). Thus the modality of the video (musical or non-musical) did not strongly impact short-term test performance.

Participants Preferred Musical Versions of the Videos

Although the musical videos did not result in higher short-term test performance scores, these versions were enjoyed more than the non-musical ones (Table 3). For three out of the four pairs of videos, enjoyment was significantly higher among participants who watched the musical version. Participants were also asked, 'If you had the chance, would you learn about other science topics by watching videos similar to the one you saw?' For two of the four pairs of videos, responses were significantly more positive among those who watched the musical version. Thus, the bottom line on Study B is that it identified a context in which music enhances enjoyment of science lessons without necessarily enhancing learning.

Study C: detailed assessment of 'Fossil Rock Anthem' music video

Methods

Research Questions

Limitations of Studies A and B included (1) the inability to measure the longer-term impact of the videos and (2) possible volunteer bias among study participants. Therefore Study C addressed the question of whether a science music video ('Fossil Rock Anthem')

teaches learners more effectively than a non-musical version, as indicated by short-term and longer-term test performance. Study C also extended Study B's exploration of whether students have different attitudes toward musical and non-musical science videos. Study C included a strong majority of students invited to participate at two New Zealand schools, thus limiting the potential influence of volunteer bias.

Creation of 'Fossil Rock Anthem' Music Video and 'Just-the-facts' Video

Both videos were created specifically for this study and were designed to cover the State of California's (USA) grade 7 Earth Sciences standard 4 ('Evidence from rocks allows us to understand the evolution of life on Earth') and its sub-parts a through g (Bruton & Ong, 2003). 'Fossil Rock Anthem' is a parody of 'Party Rock Anthem' by LMFAO (youtube.com/watch?v=Ih5AHxh-Ok), a song chosen for its catchiness and popularity among the target audience. An animated music video (MUSIC; youtube.com/watch?v=IJ5lwl_wM0) was created by one of the authors (T.M.) to display and emphasize the lyrics and to demonstrate scientific concepts via images and animation. A 'just-the-facts' video (FACTS; youtube.com/watch?v=dNmAavzwDc), consisting of spoken-word narration plus display of the text being read, was also created.

While a strong effort was made to ensure that the two videos covered equivalent content, some minor differences were unavoidable. For example, the word 'fossil[s]' was mentioned 16 times in the FACTS video but only eight times in the MUSIC video, not counting pronouns (e.g. 'they') that referred to fossils. It is possible that such subtleties affected students' perception of the content.

Schools and Participants

Seven schools in Dunedin, New Zealand, were contacted, and two schools (both coeducational and covering years 1 through 8, equivalent to grades K through 7 in the USA) agreed to participate in the study. All year 7 (Y7) and year 8 (Y8) students at both schools were given consent forms to take home, and all 87 students who brought back signed consent forms and showed up on the first day of the study were included in the research. These 87 students represent >65% of all Y7 and Y8 students enrolled at these two schools. Neither Y7 nor Y8 students at either school were formally studying earth science at the time of this study. The students were divided fairly evenly between Y7 ($N=33$) and Y8 ($N=53$; one student's year is unknown) and between females ($N=37$) and males ($N=49$; one student's sex is unknown). Regarding ethnicity, 92% of students identified as New Zealand European, 9% as Maori, 2% as Australian, 1% as Japanese, and 1% as Samoan. (Five students were multi-ethnic, so the total exceeds 100%.) Randomization within each class year at each school ensured that the MUSIC group (who watched 'Fossil Rock Anthem') and the FACTS group (who watched the 'just-the-facts' video) were balanced.

Protocol

Testing of participants was done in the school computer labs. One of the authors (T.M.) was in the room to supervise testing and troubleshoot. Each participant used a separate computer equipped with headphones. An eight-question pre-video test (see Appendix) was followed immediately by the assigned video and a post-video test/survey. While the pre- and post-video tests were identical, the post-video questions also included Likert-style items to measure students' attitude toward the video (e.g. was it fun, lame,

boring, exciting?), attitude toward the type of lesson (e.g. should this type of lesson be used more often?), motivation to learn more about the science of fossils and geological history of the earth, and desire to share the video with friends and family. We were especially interested in whether video-watching would inspire follow-up activities because development of academic interests is a multi-step process (Hidi & Renninger, 2006) that, ideally, connects academic work to other aspects of students' lives (Hulleman & Harackiewicz, 2009).

The same content test was administered again 28 days after the videos were viewed, along with additional survey questions on whether students had talked about fossils or earth sciences with their families, looked for information about fossils or earth science, and/or talked about fossils or earth sciences with friends.

Teacher Survey

Three teachers who participated in Science Idol 2012 (McFadden, 2013) and seven teachers whose students participated in the 'Fossil Rock Anthem' study were invited to complete an online survey on 'Fossil Rock Anthem'. Due to the small number of teachers surveyed, formal qualitative approaches such as coding or cross-case analysis were not used for these data.

Data Analysis

All Likert items about student opinions (Likert, 1932) offered five categorical options of how strongly a student agreed with a given item (these ranged from 'strongly disagree' to 'strongly agree'). In this study, individual Likert items were treated as ordinal, making a non-parametric test, the χ^2 test, appropriate. *T*-tests were also used to compare content scores and differences in content gain scores, as in Study A. Holm-Bonferroni corrections for multiple comparisons were applied as in Studies A and B.

Results

Contrasting Effects of Music and Non-musical Videos on Test Performance

Forty members of the MUSIC group and 41 members of the FACTS group completed all tests including the 28-day follow-up. Both groups improved significantly from the pre-video test to the immediate post-video test (paired *t*-tests, $p < .025$ for each), with the FACTS group tending to improve more (2-sample *t*-test, $p = .13$). However, after 28 days, the gains made by the FACTS group were essentially reversed, whereas the MUSIC group maintained its modest pre- to post-improvement (Figure 3). The superiority of the MUSIC group's delayed post-test scores over its pre-test scores (paired *t*-test; $p = .044$) approached statistical significance after accounting for multiple comparisons (cutoff: $p < .025$).

Question-by-question Improvement

We asked whether the science music video boosted performance on some questions more than others. Indeed, the pre- to post-video improvement was strongest for Question #1: 'Slow geologic processes require _____ in order to have a dramatic effect on the Earth'. The percentage of the MUSIC group choosing the correct answer ('long periods of time') jumped from 73% before the video to 98% after the video, while improvement

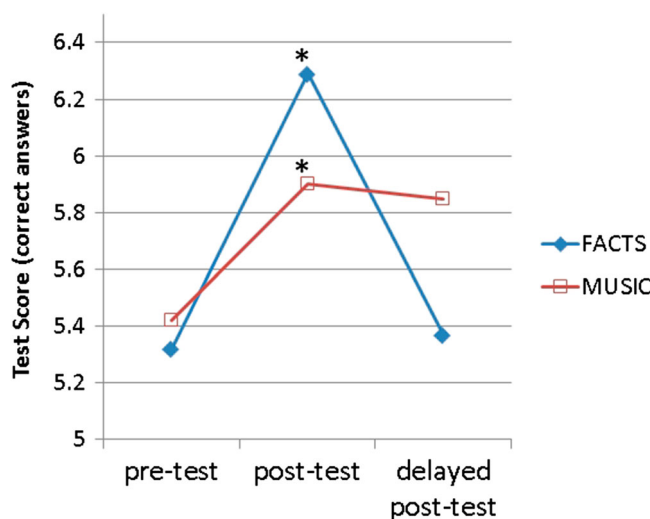


Figure 3. (Colour online) Test scores for the MUSIC and FACTS groups (Study C). Asterisks show statistically significant increases from pre-test to post-test. The difference between the delayed post-test and pre-test for the MUSIC group was not quite statistically significant after correction for multiple comparisons ($p = .044$; see text)

on every other question was 10% or less. The substantial improvement on Question #1 might stem from the song's seven repetitions of the phrase, 'Slow moves, long time'. This exemplifies a potential benefit of music, that is, that the repetition sometimes needed for learning can be achieved in a 'natural' style that students may find pleasing rather than boring. However, the FACTS group also showed considerable improvement on Question #1, climbing from 66% correct pre-video to 93% correct post-video.

General Perceptions of Videos

Both groups overwhelmingly agreed ($\geq 80\%$) with statements that the videos 'are better than learning from my normal textbook', 'should be used in science class more often', and 'are valuable ways to learn about science'. More than 80% of participants in both groups disagreed with statements that their video was 'boring' or 'lame'. Members of the MUSIC group were more likely to rate their video as 'fun' ($p = .03$) but were also more likely to agree that the video 'moved too fast' ($p = .01$). Members of the FACTS group agreed more strongly with the statement that they 'learned something new' ($p = .001$). This latter finding is consistent with the trend toward greater short-term test-score improvement by the FACTS group, but could also reflect the more explicitly didactic style of the FACTS video. In other words, students may generally associate music with entertainment rather than with education.

Desire to Engage with and Share Videos

Three items investigated students' desire to interact further with their assigned video (Figure 4). The largest (approaching statistical significance) difference occurred on the question of whether students would watch the video again at home, with the MUSIC group tending to answer more affirmatively (χ^2 test, $df = 4$, $p = .07$). When asked

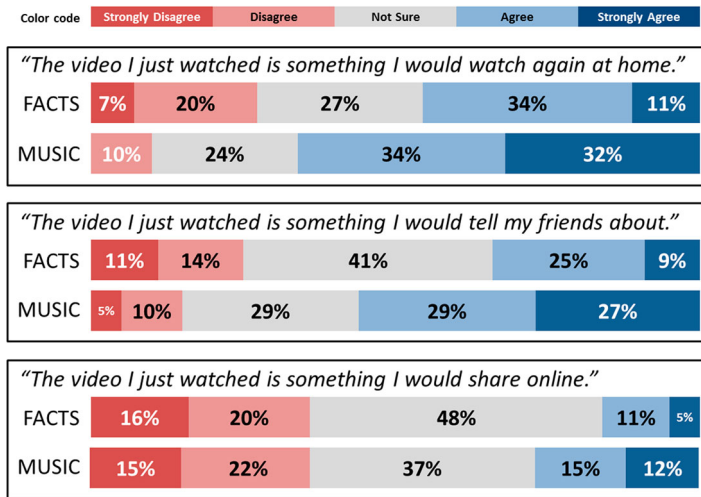


Figure 4. (Colour online) Students' interest in interacting further with their assigned video (Study C). When the MUSIC and FACTS groups were compared with χ^2 tests ($df = 4$), P -values were 0.07 (top), 0.19 (middle), and 0.67 (bottom)

whether the video was something they would tell their friends about, most students in the MUSIC group agreed, while many students in the FACTS group were not sure. Students in both groups were less sure about sharing their videos online.

Some possible reasons for the tendency toward heightened shareability of the music video can be found in the MUSIC group's answers to 'Fossil Rock Anthem'-specific questions. Almost all (93%) of these students were familiar with the song being parodied, 'Party Rock Anthem'. There was near-unanimous (98%) agreement that the 'Fossil Rock Anthem' was catchy, and most (88%) reported that the song was still stuck in their head while filling out the rest of the questionnaire. Interestingly, the majority of students (78%) reported paying close attention to the meaning of the lyrics, even while comparing these lyrics to the original 'Party Rock Anthem' song. This displays one of the key benefits of parodying a song that students are already familiar with. First of all, the original song is popular because it is catchy, so the science version will benefit from much of that same catchiness. Second of all, students are already familiar with the structure of the original song, and this familiarity may allow students to pay more attention to the lyrics of the science version, though further investigation is required to explore this hypothesis. Finally, the song's familiarity may also facilitate repeated singing of the song as a form of studying because the students do not have to learn a new melody from scratch. In any case, for this particular study, it seems plausible that the popularity and familiarity of the original song contributed to students' above-mentioned desire to interact with it further.

These findings from Study C are broadly consistent with participants' ratings of the Study A videos, among which 'Fossil Rock Anthem' was considered one of the most enjoyable (Table 1). The other parody songs—about the Nervous System and Chemical Ecology—were also rated relatively highly by participants (≥ 3 on a 4-point scale), suggesting that parodies may indeed be broadly enjoyable.

Interaction with Science Following the Video

As part of the day-28 follow-up, students were asked whether they had talked about fossils or earth sciences with their families, looked for information about fossils or earth science, and/or talked about fossils or earth sciences with friends. Most students in both the MUSIC and FACTS groups answered 'never' or 'almost never' to all three questions, though FACTS students were significantly more likely to respond positively to the first item (χ^2 test, $df = 4$, $p = .002$). This may reflect the fact that the word 'fossils' was used twice as often in the FACTS video as it was in the MUSIC video. When these three questions and three additional questions about students' frequency of thinking about these topics were combined into an 'interaction with science' scale, 28% of students in the MUSIC group (11 of 39) scored 0 on the 24-point scale, as compared to 7% of FACTS students (3 of 41). Thus, even though the music video was enjoyed by nearly all of the MUSIC students, that enjoyment did not necessarily translate into additional pursuit of the science.

Teacher Reactions to 'Fossil Rock Anthem'

All teachers surveyed ($N = 10$) responded favorably to 'Fossil Rock Anthem', with 100% reporting that they would use such a video in their class. Several teachers commented on the use of imagery and visual lyrics to help convey concepts. Non-Science Idol teachers ($N = 7$) were also asked whether the video could be used as an introduction to a unit; 71% said yes. The same percentage thought the video would be an engaging way to 'hook kids in' to a unit. Many (57%) also thought the video would be useful as a summary at the end of the unit. When given the open-ended opportunity to report on other ways of incorporating such a video, one teacher offered several diverse ideas: (a) have students write down what they know before watching the video and then revisit and revise the list after the video; (b) print out the song lyrics with blanks for students to fill in; (c) split the class into groups and have each group perform a different section of the song; (d) use 'Fossil Rock Anthem' as an example of a science song and then have students write their own songs covering subtopics in greater detail.

Results Summary

Students in both the MUSIC and FACTS groups showed statistically significant pre-test to post-test gains. Though the FACTS group showed possibly greater immediate improvements than the MUSIC group, their gains appeared to be short-lived, whereas the MUSIC group tended to maintain their post-test improvements for 28 days. There appeared to be widespread enthusiasm for the MUSIC video among both students and teachers.

Discussion

The three studies reported in this paper contribute new insight into the educational value of using music to teach science concepts. Study A essentially documented that students can learn science content in a single pass through a two- to four-minute science music video outside of a formal classroom setting. Study B suggested that, in the short term, such videos improve test performance about as much as non-musical versions, and may be more enjoyable. Study C confirmed that students can learn at least as much from a

non-musical science music video as from a musical one, but suggested that the impact of the musical video on learning might last longer.

Among videos aimed at grades 3–5 in Study A, the lyrics-only versions improved test performance at least as much as the corresponding visually rich versions. This finding can be taken as good news for educators, who do not need to provide elaborately staged videos if simpler ones work just as well. We speculate that, if the videos were shown repeatedly, visually rich versions might sustain students' interest more effectively than lyrics-only versions. However, the lyrics-only versions have the advantage of focusing students on the (verbal) content to be learned.

Our most intriguing finding arguably came from Study C, in which the comprehension gains made by the FACTS group were basically erased after 28 days, whereas the MUSIC group tended to maintain their pre- to post-test improvements. Earlier research on the connection between emotion and memory and the role of repetition in memorization may help to explain the possible long-term benefits associated with watching the music video, as opposed to the non-musical narration of science concepts (Calvert & Tart, 1993; Cirigliano, 2013; Jensen, 2005; Sousa, 2006). However, in the current study, the single pass through each video limited the extent to which repetition could aid memorization (see below).

Studies B and C also found evidence to support the motivational power of music. In Study B, musical videos were generally rated as more enjoyable than equivalent non-musical versions. In Study C, analyses of the measures of engagement revealed that students in the MUSIC group were generally more engaged than those in the FACTS group. Specifically, students who watched the music video were more likely to rate the video as 'fun', and they were more likely to express interest in interacting further with their assigned video. This engagement is likely attributable to students' stated familiarity with the song being parodied as well as their judgment that the song was catchy and became stuck in their head. Teachers also agreed that the music video was an effective way to 'hook kids in' to a science unit. These findings are consistent with earlier research showing that music can be used to engage students and help them to find a personal connection to science (Albers & Bach, 2003; Emdin, 2010; Stovall, 2006). Forming a personal connection to science plays an important role in promoting science learning (Donovan & Bransford, 2005; National Research Council, 2009).

Collectively, these results provide evidence for the utility of using science music videos to teach science concepts. Music videos represent an alternative teaching strategy, which earlier research has found to be more effective at promoting student learning than traditional strategies involving textbooks and one-way teacher lectures (Wise & Okey, 1983; Wise, 1996). In particular, music videos provide students with a new entry point into and means for engaging with science concepts. According to MI theory, such diverse entry points offer individuals new opportunities to draw on their cognitive strengths and deepen their conceptual understanding (Gardner, 1983, 1999). By tapping into students' musical intelligence, science music videos expand the range of cognitive strengths used in science education. As a result, students whose intelligence profiles have not previously led to success in traditional science classes may find new opportunities for success in classes that incorporate music. The theory of semiotic mediation offers an additional lens through which to view music's positive effect on science learning (Holland,

1998; Vygotsky, 1978). As culturally constructed artifacts, music videos may help students to gain control over their cognitive processes.

Not all results from Studies B and C favored the science music videos. In neither case did music-exposed participants outperform other participants in immediate post-video tests. In addition, students in the FACTS group of Study C were more likely than students in the MUSIC group to agree that they 'learned something new'. Though the 28-day test results suggest otherwise, it is possible that the narrative and text-based format of the FACTS video created an impression that it was conveying a greater amount of information. Students in the FACTS group were also more likely to interact with the science content following the video. This difference highlights the challenge of translating students' immediate engagement with a science music video into a longer-term propensity to engage with the scientific concepts when they are separate from the video.

Limitations and Future Directions

The studies summarized here had complementary strengths and limitations. While Studies A and B investigated a variety of music videos aimed at different ages, they did not assess the longer-term impact of these videos. Conversely, Study C did include a 28-day follow-up, but only studied a single music video. Since several findings in Studies A and B were consistent across multiple videos and age groups, we are relatively confident in their generality, whereas Study C's results can be considered more preliminary. It would be highly informative to apply Study C's model of longer-term follow-up to additional videos covering more topics and age groups.

An additional limitation of Studies A and B is that possible effects of volunteer bias cannot be excluded. It is plausible that music fans were more likely to participate in our voluntary activities than non-music fans, and that music fans benefited more from the videos than non-music fans would have. At the very least, our data suggest that musical activities can stimulate learning among those who seek it out, and can be offered by teachers as optional enrichment assignments. Moreover, volunteer bias is much less of a concern for Study C, since consenting students and parents were not aware ahead of time that the study would involve music and since >65% of all students in the targeted classes participated.

An important limitation of all three studies was the fact that the educational intervention consisted of a single, short video that was not connected to any classroom activities. While this study design allowed us to collect data with little or no intrusion upon classroom teachers, it did not maximize the benefits of such videos. We suspect that if teachers select specific music videos that match their curricula well, provide context for these videos, and distribute and discuss their lyrics with their students (Crowther & Davis, 2013; Governor et al., 2013), much more profound and long-lasting effects could be seen. That is, while the moderate short-term knowledge gains reported here might seem unsurprising, they might best be taken as just a hint of the more profound transformations that might arise from integrating music into existing science curricula. Thus, future research might profitably focus on issues of integration and reinforcement. One practical question that could be studied is whether stand-alone science music videos can easily be integrated by most teachers into existing lessons, or whether such videos will largely go unused unless bundled with lesson plan suggestions.

An additional aspect of Studies A and C that could be seen as a potential limitation is that the pre-video test may have signaled to participants what specific content from the song they should retain for the post-video test. We assume that some participants did indeed benefit from this signaling. In our view, starting an activity by indicating what we want students to learn is an appropriate and useful teaching strategy; still, it does not guarantee that students will actually learn what we want them to learn. Therefore these ‘guiding questions’ reflect authentic educational practice, as well as being a specific mechanism to increase students’ acquisition of knowledge from videos (Lawson, Bodle, Houlette, & Haubner, 2006).

Conclusion

The current state of science education points to a need for new pedagogical strategies to engage students on a personal level and deepen their understanding of science concepts. The findings reported in this paper provide evidence that music can achieve both goals. Across age, gender, and venue, watching science music videos resulted in student gains in pre- to post-video test performance. Study A showed that students increased their performance on both ‘comprehension’ and ‘knowledge’ questions. Studies B and C indicated that addition of music to science videos enhanced engagement and produced learning gains which may last at least 28 days. These results have relevance for teachers, policy-makers, and researchers seeking innovative ways to improve science education.

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