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Rocks Really Rock: electronic field trips via Web Google Earth can generate positive impacts in attitudes toward Earth sciences in middle- and high-school students

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Abstract. Earth sciences (ESs) are relevant to society and its relationship with the Earth system. However, ES education in K-12 environments in the United States faces several challenges, including limited exposure to ESs, lack of awareness of ES careers, and low ES literacy. International associations have recognized these challenges and recommended that Earth scientists improve the public's perception of the relevance of ES. In recent years, informal science communication and outreach platforms such as the Streaming Science model of electronic field trips (EFTs), which connect K-12 classrooms with science, engineering, technology, and mathematics (STEM) professionals, have gained popularity as an educational technology tool. EFTs are inexpensive, have spatiotemporal benefits, and have proven an effective informal science education pathway for introducing STEM content into formal classrooms to increase positive attitudes and interest in STEM careers. Nevertheless, EFTs in ES for K-12 environments have not been widely disseminated, and their impact on ES education has yet to be studied.

This study presents the creation and implementation of an EFT in geology called "Rocks Really Rock: An Electronic Field Trip across Geological Time." The program was implemented in seven schools in spring 2022. The EFT was built in Web Google Earth and had six stops that featured prerecorded videos recorded in different locations in Idaho (USA). The lead presenter or author used multimedia and science communication strategies such as storytelling to develop and teach concepts related to geological time, rock formation, and landscape-forming geological processes. The content aligned with four specific topics listed in the National Science Foundation's Earth Sciences Literacy Principles and intersected with the Next Generation Science Standards for middle-school classrooms.

Participating students ($n = 120$) completed a post-assessment after the program implementation to evaluate its impact. Results showed that the EFT positively impacted students' attitudes toward geology, geology careers, and perceptions of geology literacy. We identified the three main factors that determined a positive attitude change in K-12 students toward ES: (1) the use of videos and the Web Google Earth platform to create outreach materials for K-12 students, (2) the use of storytelling to craft the content of an EFT, and (3) the asynchronous interactions between teacher, student, and scientist. The results indicated a statistically significant positive change in attitudes toward geology, suggesting that participating in the EFT increased students' positive attitudes toward ES. These findings demonstrate the potential of expanding EFT to other ES fields and reaching middle- and high-school students. We suggest that EFTs are effective outreach tools that can address the challenges in ES education and that can be extended to other ES areas and distributed to students in middle, high, and home schools to support science educators in ES education.

1 Introduction

Earth science (ES) education in US K-12 environments faces multiple challenges, such as (1) low exposure to ES in the science curricula, (2) low awareness of ES careers, or (3) poor literacy of ES concepts (Adetunji et al., 2012; Hoisch and Bowie, 2010; LaDue and Clark, 2012). K-12 is used in reference to the US education system for students from ages 5 to 18 attending grades between kindergarten and 12th grade, but this is not solely a US reality. In fact, international associations, ES educators, and K-12 teachers have recognized these barriers (GSA Position Statement, 2013; King, 2013; LaDue and Clark, 2012; Petcovic et al., 2018), and they have emphasized the need to strengthen K-12 ES education, develop ES-literate citizens, and advocate for the implementation of informal science learning strategies (outreach) in K-12 environments. However, there are few studies that have quantitatively assessed the impact of individual ES outreach strategies on students.

ES outreach via electronic field trips (EFTs) is a potentially effective way to address some of the challenges in ES K-12 education. In recent years, the outreach format of EFTs has grown in popularity, engaging K-12 students and teachers in two-way conversations with subject matter experts. EFT models such as the Streaming Science model have proven to be an effective outreach pathway for delivering science, engineering, technology, and mathematics (STEM) content to formal education environments such as K-12 classrooms (Adedokun et al., 2011; Beattie et al., 2020; Loizzo et al., 2019). The adaptability of delivering content in multiple formats (e.g., live-stream or prerecorded video) and the ability of EFTs to use science communication (scicomm) strategies (e.g., digital multimedia, storytelling) have proven to have a positive impact on students' perceptions and attitudes toward scientists, science careers, and science overall (Beattie et al., 2020; Dahlstrom, 2014; Loizzo et al., 2019). These changes in attitudes and perceptions can simultaneously influence interest in related careers and learning (Lyon et al., 2020; McNeal et al., 2014). Collectively, these findings demonstrate that the use of EFTs provides a unique opportunity to develop informal ES learning tools and bring them into formal K-12 education environments.

In the following study, we present the creation, implementation, and evaluation of a prerecorded EFT in geology topics created in Web Google Earth called "Rocks Really Rock: An Electronic Field Trip across Geologic Time". The EFT introduced middle-school and high-school students to the concepts of geological time, rock formation, and landscape-forming geological processes. The EFT had six designed stops shown on a map of the United States. Each stop featured a prerecorded video of the lead author, who used science communication storytelling strategies to explain geology-related topics that aligned with four specific topics listed in the Earth Sciences Literacy Principles (ESLP) (Wysession et al., 2012). The geology topics intersected with the Next Generation Science Standards for middle-school classrooms (National Research Council, 2013). In addition, we examined the implementation of the EFT using a quantitative design and evaluated the impacts of the program on K-12 school students via a post-assessment survey in three main areas: (a) attitudes toward geology, (b) attitudes toward geology careers, and (c) perceptions of geology literacy.

2 Background literature

2.1 Challenges of ES education and the role of outreach and science communication

Literacy and awareness of ES topics (e.g., atmospheric sciences, climate sciences, planetary sciences, environmental sciences, geology, or oceanography) are essential to understanding critical societal challenges related to the Earth system, including climate change, natural resource management, natural hazards, access to reliable and safe mineral and energy sources, and planetary exploration, among others (Clary, 2018; Tillinghast et al., 2019; Wysession et al., 2012). Building an ES-literate society depends on high-quality education, and K-12 school settings have the potential to reinforce positive attitudes toward ES content and careers and build ES literacy (King, 2013; Levine et al., 2007; St. John et al., 2021; Tillinghast et al., 2019). However, only a small percentage of students receive formal education in ES, even in developed countries such as the UK and the United States (Gates and Kalczynski, 2016; Rogers et al., 2024). In the latter, for example, literacy in ES is particularly low compared to other scientific disciplines in other countries (Gates and Kalczynski, 2016; Gonzales and Keane, 2011; LaDue and Clark, 2012; OECD, 2019). Furthermore, in countries located in southern Europe and Latin America, geology courses must share teaching time with other science disciplines, and in countries such as Australia, geology courses are only available as additional or optional courses (Roca and Garcia-Valles, 2020; Dawborn-Gundlach et al., 2017).

Low exposure to ES content in K-12 environments also impacts the lack of awareness of ES careers among both students and teachers as well as the difficulty students have connecting science classroom content to career pathways (Brown and Clewell, 1998; Levine et al., 2007; Gonzales and Keane, 2011; Sherman-Morris et al., 2013; McNeal et al., 2014; Locke et al., 2018; King et al., 2021). Recent international comparative studies show that three-quarters of the countries surveyed recorded that students have very little or no career advice related to ES (King et al., 2021). For example, geology, a branch of ES, has had the lowest numbers for major recruitment compared to other STEM careers in the last decades (Levine et al., 2007; Locke et al., 2018), which may be related to an international overall reduction in university-level ES careers and courses (Geoscience on the chopping block, 2021; Rogers et al., 2024).

Several studies suggest that students who choose to study STEM majors generally make the decision during high school and even earlier (Maltese and Tai, 2011; Tai et al., 2006; Villaseñor et al., 2020). Thus, growing interest in ES and improving recruitment to ES careers should begin with increased exposure to engaging STEM content, careers, or majors and raised awareness of future pathways during middle and high school. Several strategies have been developed to support formal ES education and increase awareness and literacy such as integrating ES literacy standards into traditional science courses (Hanks et al., 2007; Levine et al., 2007; McNeal et al., 2014). For example, in 2011, various Earth scientists and educators created the ESLP (Wysession et al., 2012).

The American Geosciences Institute (AGI) has been in charge of disseminating the ESLP, which define the important and essential ES information to be taught, to K-12 ES teachers (Wysession et al., 2012). Furthermore, in the US, the Framework for K-12 Education (National Research Council, 2012) and the subsequent release of the Next Generation Science Standards (NGSS) created a guide for the core ideas and practices that all K-12 students should learn before graduating from high school (NGSS Lead States, 2013). The implementation of these standards introduced a significant amount of ES content into the high-school curriculum and increased the emphasis on ES (LaDue and Clark, 2012; Lyon et al., 2020). However, even though the NGSS have placed ES as a core component of the secondary science curriculum, several challenges remain, including the lack of understanding or misunderstanding of ES-related concepts among college-bound students (Pyle et al., 2018), the deficiency of ES instructional resources, the lack of support for school-level ES instruction from the science education community, and the lack of ES-focused teacher training (King, 2013).

Altogether, these challenges in ES education show a need for new approaches to support the ES K-12 curriculum (King, 2013), such as the reinforcement of students' positive attitudes toward ES through outreach and scicomm. Positive attitudes toward science are a set of affective behaviors such as (1) the manifestation of favorable attitudes toward science and scientists, (2) the enjoyment of science learning experiences, (3) the development of interest in science and science-related activities, and (4) the interest in pursuing a career in science. These behaviors can influence students' interest in science careers and in STEM learning (Fitzakerley et al., 2013; Lyon et al., 2020; McNeal et al., 2014; Osborne et al., 2003). Researchers have commonly measured attitudes toward science using questionnaires with Likert-scale items, which ask students to use a rating scale to indicate a favorable or unfavorable opinion about a statement. The ability to use these responses in statistical analysis has made them a widely used and reliable tool for measuring attitudes toward science topics (Osborne et al., 2003).

Moreover, outreach and scicomm have the potential to have a positive impact on the development of positive attitudes toward ES careers and ES literacy. Outreach refers to the activities or processes whose main objective is to promote awareness of STEM in real life, the pursuit of STEM careers, and motivation of non-experts to learn STEM topics (Crawford et al., 2021; Jeffers et al., 2004; Vennix et al., 2017). Outreach programs can take place in person or virtually and can be structured in a variety of ways and formats (Crawford et al., 2021). Examples of outreach initiatives include science art installations in nontraditional locations such as public parks (Arcand and Watzke, 2010), the creation of audiovisual material distributed through social media platforms (Gurer et al., 2023), or hands-on experiences in nature preserves or museums (Stocklmayer, 2005). Regardless of their structure or format, outreach activities can use scicomm strategies to achieve these goals, as they have the potential to increase the comprehension (literacy), interest, and engagement of non-expert science learners (Dahlstrom, 2014) and can be used to increase positive attitudes toward STEM subjects and careers (Burns et al., 2003; Choi et al., 2020; Schmidt and Kelter, 2017). In addition, if the scicomm strategies are aligned with specific learning goals, they can have a positive impact on content area literacy (Hildenbrand, 2022).

2.2 EFTs

Digital outreach strategies such as EFTs have shown the potential to extend scientific research and information about science concepts and careers to a range of formal, informal, and non-formal audiences, allowing viewers to visit virtually any location around the globe (Beattie et al., 2020; Cassady and Kozlowski, 2008; Evelpidou et al., 2021). For example, the Streaming Science Project is a globally available online outreach platform that includes college-student-created EFTs and other multimedia to introduce audiences to STEM topics and experts. The Streaming Science EFT model (Loizzo et al., 2019) connects science experts with K-12 students by showcasing live webcasts or prerecorded videos from various science fields. Using this approach, the Streaming Science EFT model has positively impacted students' perceptions and attitudes about scientists, science careers, and science in general (Barry et al., 2022; Beattie et al., 2020; Loizzo et al., 2019). WordPress analytics show that more than 137 countries have viewed the Streaming Science overall website since the project began in 2016, and the Rocks Really Rock EFT website had 697 views during 2022–2023, when it was heavily promoted to schools. Science communication materials and outreach programs are publicly available and free as they are often supported through grant funding and faculty and college student research.

EFTs can follow different technology formats, from partially to fully immersive augmented reality experiences (usually referred to as virtual field trips) to both prerecorded and live-streaming video broadcasts, and they can be created using different platforms (e.g., ArcGis Stories, desktop and Web Google Earth, and virtual reality platforms). Previous studies have shown that students can benefit from virtual field experiences, which have several advantages over in-person field trips, such as (1) accessibility to learners with all types of abilities and socioeconomic backgrounds, (2) accessibility from any part of the world with an Internet connection, (3) suppression of logistics of in-person field trips such as time, transportation, and high costs; (4) availability when sites cannot be visited due to safety conditions, time, weather, or health reasons; and (5) the ability of the audience to move through the content at their own pace (Carabajal et al., 2017; Cliffe, 2017; Evelpidou et al., 2021; Pugsley et al., 2022).

EFTs in ES-related topics have been created for formal education at the college level, collecting and processing visual, spatial, and informational data on a geological site of interest with which the user can interact to varying degrees (Barth et al., 2022; Dolphin et al., 2019). Some of these virtual field trips have been created to substitute classic field guides (e.g., *Streetcar to Subduction to the San Francisco Bay Area*) or to provide remote alternatives to real, in-person field trips in formal ES field education (e.g., virtual field trips during the COVID-19 pandemic) (Bond et al., 2022). These virtual experiences combine digital narratives with geological fieldwork observations, introduce information about a geological field site, and provide an authentic sense of being at real geological sites (Cliffe, 2017; Dolphin et al., 2019; Granshaw and Duggan-Haas, 2012). Nevertheless, most of these EFTs have been used as alternative education in ES majors, but they have not been designed with outreach in K-12 environments in mind. Thus, EFTs have the potential to become a widely used outreach strategy in both informal and formal learning environments, following pre-established models for K-12 outreach through EFTs, such as the Streaming Science model (Beattie et al., 2020; Loizzo et al., 2019).

This study examined the development, implementation, and assessment of the EFT called Rocks Really Rock: An Electronic Field Trip across Geologic Time. The EFT followed the Streaming Science EFT model (Loizzo et al., 2019) and a quantitative design to assess the impact of the program on K-12 school students through a post-survey in three main areas: (a) attitudes towards geology, (b) attitudes towards geology careers, and (c) perceptions of geology literacy. The collaboration between scientists and K-12 environments, which this model has successfully tested in several contexts (Aenlle et al., 2022; Barry et al., 2022), provided a platform to positively impact students' attitudes and perceptions toward ES and ES careers using EFTs. In the next section, we describe the development of the EFT and the survey data collection in detail.

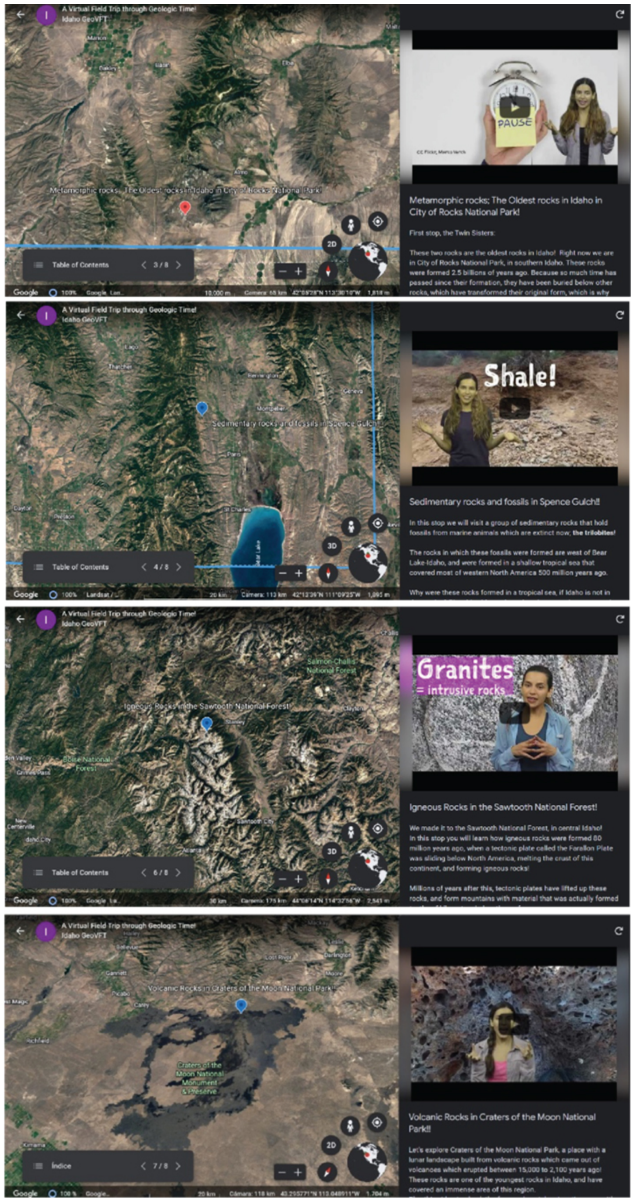

Figure 1. Screenshots from the EFT "Rocks Really Rock: An Electronic Field Trip across Geologic Time". Adapted from https://earth.google.com/earth/d/1btfkYpOkcsqQktfky-t0pYJLT1e2lJSP?usp=sharing (last access: 19 September 2023). © Google Earth 2023.

3 Methods

3.1 EFT context and content development

This study developed, implemented, and assessed the EFT called Rocks Really Rock: An Electronic Field Trip across Geologic Time whose target audience was middle- and high-school students. The EFT consisted of six single-presenter explanatory videos (recorded in Idaho, USA, in summer 2021) embedded in a Web Google Earth project, an open-access tool that allows project creators to geotag locations around Earth and embed multimedia content. Each of the videos was linked to a specific geographical stop with geological significance within the context of the EFT content (Fig. 1). The lead author used a storytelling approach to present the content at each of the stops, following chronological order to tell the story of geological changes on Earth that are observable in the rocks found in the field. The entire EFT took approximately 40 to 45 min and was publicly available online (see the Supplement).

Figure 2. Screenshot from the Streaming Science web page for the Rocks Really Rock EFT. Adapted from https://streamingscience.com/rocks-really-rock-an-electronic-field-trip-across-geologic-time/ (last access: 19 September 2023).

The expertise of the subject matter expert (this article's lead author) in the field of geology of Idaho was instrumental in developing the EFT. Ortiz-Guerrero has an academic background in geology and was in the process of finalizing her Ph.D. when she developed the program and assessment. This academic pursuit allowed her to acquire in-depth knowledge and expertise in the subject of the EFT. Furthermore, the EFT content featured her rock research and field sites in Idaho, and thus she was familiar with the regional geological features and their history, which allowed the authors to create a targeted and engaging learning experience for the K-12 students.

The EFT geology content was designed to align with the NGSS learning objectives in the Middle School Earth Sciences (MSESS) disciplinary core ideas, from three subcategories: (1) The History of Planet Earth, (2) Earth's Material and Systems, and (3) Plate Tectonic and Large-Scale System Interactions (National Research Council, 2012; NGSS Lead States, 2013). These NGSS standards also intersect with several of the Big Ideas listed in the National Science Foundation (NSF) ESLP (Wysession et al., 2012). Table 1 summarizes the integration of these educational and Big Idea standards, which resulted in the design of the EFT incorporating four key Big Ideas from the ESLP. The characteristics of each video, the recording location, and the associated ESLP and NGSS objectives are summarized in Table 2. A unique subwebsite for the EFT was created on the Streaming Science platform, which included a description of the program, links to a registration form, and the teachers' guide. The teachers' guide was designed as a standalone document that included instructions for K-12 educators to go implement the EFT in their classrooms.

Storytelling applied to science invites scientists to share their research and learning experiences with audiences through narratives, making science more accessible and engaging. The overall goal of using storytelling to explain geology literacy content was to describe selected concepts from the NGSS in the context of geochronology and geology careers. Geochronology, referred to by some as "the heart of the earth sciences" (Harrison et al., 2015), is the discipline that frames the geological events of Earth in chronological order. Therefore, by framing the chosen geological concepts within a geochronological order, the audience was able to follow a narrative arc structure of beginning, middle, and end, allowing the audience to follow the simple idea of what happened next and learn through the story of Earth's changes. In summary, the script was constructed to give the audience a reason and a causal connection between the different geological events at each of the stops, distilling the information to construct a compelling story in a non-formal language appropriate to our target audience. In addition to the geological story, we introduced the audience to geological careers by explaining the work of a geologist using the "AND–BUT–THEREFORE" (ABT) conceptual storytelling structure (Olson, 2015).

The ABT storytelling strategy structures the flow of information by forming a narrative arc in the audience's mind, avoiding an expository flow of information. In this method, the beginning of the story presents facts that are connected by "ANDs", which represent an agreement between the facts. In the middle of the story, the antithesis or problem of the story is introduced by the word "BUT". Finally, the end of the story follows the antithesis with a solution and is introduced by the word "THEREFORE" (Olson, 2015). This part gives way to the beginning of the journey, the consequence that leads the storyteller to the explanation of why we do what we do. To apply this structure in this project, the ANDs were communicated as geological scientific facts, e.g., "The history of Earth is recorded in the rocks of Earth". The BUT is communicated as an antithesis, e.g., "But geological processes take place on non-human timescales, so we cannot see them". Finally, the THEREFORE is communicated as a solution: "Therefore, geologists study Earth by going into the field and looking at rocks to study Earth's history".

Table 1. List of Earth Sciences Literacy Principles (ESLP) and Next Generation Science Standards (NGSS) used for content literacy in the "Rocks Really Rock" EFT.

ESLP	Middle School Earth Sciences (MS-ESS) NGSS standards used in content creation
Big Idea 2: Earth is 4.6 billion years old.	MS-ESS1.C – The History of Planet Earth MS-ESS2.A – Earth's Material and Systems MS-ESS2.B – Plate Tectonic and Large-Scale System Interactions
Big Idea 3: Earth is a complex system of interacting rock, water, air, and life.	MS-ESS1.C – The History of Planet Earth MS-ESS2.A – Earth's Material and Systems MS-ESS2.B – Plate Tectonic and Large-Scale System Interactions
Big Idea 4: Earth is continuously changing.	MS-ESS1.C – The History of Planet Earth MS-ESS2.B – Plate Tectonic and Large-Scale System Interactions
Big Idea 6: life evolves on a dynamic Earth and continuously modifies Earth.	MS-ESS1.C – The History of Planet Earth

3.2 Research design

3.2.1 Participant recruitment

Teacher and student recruitment was conducted after approval by the Institutional Review Board for Human Subjects Research at the University of Florida. Teachers in K-12 schools in the US were recruited to participate in the EFT using the following methods: (1) direct email invitation through the Streaming Science educators' listserv in MailChimp, (2) direct email invitation to educators through the Scientist in Every Florida School program of the Thompson Earth Systems Institute at the Florida Museum of Natural History, (3) Streaming Science social media accounts, and (4) word of mouth through the lead author's personal contacts.

After teachers registered their classrooms for the EFT and indicated their interest in participating in the research, they were emailed a link to the website, teachers' guide, and EFT content. Approved opt-out consent forms were sent home to parents informing them of their child's participation in the EFT and in the anonymous research. Parents who did not want their child to participate had the option of signing and returning the forms to the school. After the forms were returned, teachers implemented the EFT and completed the post-surveys as part of their normal classroom instruction.

3.2.2 Survey design

The student post-assessment followed a quantitative design to evaluate the impact of the program on K-12 school students through a post-survey in three main areas: (1) attitudes toward geology, (b) attitudes towards geology careers, and (3) perceptions of geology literacy. We used a post-retrospective survey design approach which consisted of a questionnaire completed by the students after completing the program. Students were asked to use a rating scale to indicate a favorable or unfavorable opinion about a statement (also known as Likert-scale items). The ability to use these responses in statistical analysis has made them a widely used and reliable tool for measuring attitudes toward science in outreach research (Adedokun et al., 2011; Aenlle et al., 2022; Barry et al., 2022; Lyon et al., 2020; Osborne et al., 2003). In addition, a teacher post-assessment was also implemented to evaluate the teachers' perceptions of the EFT and to collect suggestions for improving the program. This survey included one open question.

Several questions and statements for the post-retrospective assessment were adapted from previous ES education studies and EFT studies related to the Streaming Science project (Adedokun et al., 2011; Lyon et al., 2020; Tillinghast et al., 2019). The student and teacher surveys are available as Supplements S1 through S4. Surveys were implemented using Qualtrics, an online survey platform. The survey link was distributed via email to teachers who had registered to participate. Teachers and students completed the survey electronically or through paper copies that were scanned and sent to the researchers.

3.2.3 Data analysis

Descriptive statistics were used to analyze the quantitative survey data. Paired t tests with means and p values were calculated to compare the before and after student responses to the same question. The t test compares the means between two related groups on the same continuous dependent variable. The greater the magnitude of the t value, the greater

Table 2. Structure of the Rocks Really Rock EFT.

Video duration (m/s)	Recording location	Covered topics, ESLP, and NGSS	Learning objectives
1. Intro (2 m 24 s)	Studio	This module is an introduction to the program and to the concepts of geological time and plate tectonics. ESLP: Big Idea 2 (Earth is 4.6 billion years old) and Big Idea 3 (Earth is a complex system of interacting rock, water, air, and life) NGSS: MS-ESS1.C, The History of Planet Earth	1. Recall what the geological timescale is.
2. Stop 1 "City of Rocks, Looking for the oldest rocks in Idaho" (5 m 29 s)	Twin Sisters rocks at City of Rocks National Park (Idaho, USA) + studio	This module covers three different topics: (1) the age of the oldest rocks in Idaho, (2) the differences between today's Earth and Earth 2 billion years ago, and (3) the concept of metamorphism. ESLP: Big Idea 2 (Earth is 4.6 billion years old) and Big Idea 4 (Earth is continuously changing) NGSS: MS-ESS1.C, The History of Planet Earth, and MS-ESS2.A, Earth's Material and Systems	1. Recall what a metamorphic rock is. 2. Recall how old the oldest rocks in Idaho are.
3. Stop 2 "Cambrian Fossils" (5 m 21 s)	Spence Gulch (Idaho, USA) + studio	This module covers four different topics: (1) changes in Earth from 2000 to 500 Ma, (2) the Cambrian Earth and the Cambrian explosion, (3) formation of sedimentary rocks, and (4) formation of fossils and ichno-fossils. ESLP: Big Idea 2 (Earth is 4.6 billion years old), Big Idea 4 (Earth is continuously changing), and Big Idea 6 (Life evolves on a dynamic Earth and continuously modifies Earth) NGSS: MS-ESS1.C, The History of Planet Earth, MS-ESS2.A, Earth's Material and Systems, and MS-ESS2.B, Plate Tectonic and Large-Scale System Interactions.	1. Recall what a sedimentary rock is. 2. Recall what a fossil is and what a trilobite is. 3. Recall what the Cambrian explosion was.
4. Subduction zone and plate tectonics (2 m 57 s)	Studio	This module explains the formation of subduction zones and the occurrence of a subduction zone in the Cretaceous in western North America. ESLP: Big Idea 2 (Earth is 4.6 billion years old) and Big Idea 4 (Earth is continuously changing) NGSS: MS-ESS1.C, The History of Planet Earth, MS-ESS2.A, Earth's Material and Systems, and MS-ESS2.B, Plate Tectonic and Large-Scale System Interactions	1. Recall the effect of the movement of plate tectonics in changing the shapes of continents.

Table 2. Continued.

Video duration (m/s)	Recording location	Covered topics, ESLP, and NGSS	Learning objectives
5. Stop 3 "Igneous Rocks in the Sawtooth Mountain" (6 m 13 s)	Sawtooth Lake in Sawtooth National Forest (Idaho, USA) + studio	This module covers four topics: (1) plate tectonics 80 million years ago in the Cretaceous, (2) formation of igneous rocks in subduction zones, (3) minerals forming granitic rocks, and (4) geology methods for outcrop rock observation. ESLP: Big Idea 2 (Earth is 4.6 billion years old) and Big Idea 4 (Earth is continuously changing) NGSS: MS-ESS1.C, The History of Planet Earth, MS-ESS2.A, Earth's Material and Systems, and MS-ESS2.B, Plate Tectonic and Large-Scale System Interactions	1. Recall what a subduction zone is and the effects on mountain formation. 2. Recall what an igneous rock is.
6. Stop 4 "Origin of volcanic rocks" (6 m 14 s)	Craters of the Moon National Park (Idaho, USA) + studio	This module covers two topics: (1) formation of volcanic extrusive rocks and (2) formation of lava tubes. ESLP: Big Idea 4 (Earth is continuously changing) NGSS: MS-ESS1.C, The History of Planet Earth	1. Recall what type of rock a basalt is. 2. Recall what lava tubes are.

the difference between the means. Conversely, the closer the t value is to 0, the more likely it is that there is no significant difference between the means. Each t value has an associated p value that indicates the statistical significance of the t, with $p < 0.05$ being a statistically significant analysis. The selected valid responses were coded as a data set and analyzed in the SPSS (Statistical Package for the Social Sciences) software to calculate means, standard deviations, t tests, and p values.

Several limitations were identified in this study. First, there was the sample size of the participating schools. Although 41 teachers and classrooms expressed interest in the program, only six classrooms completed the program. Second, some of the students did not complete the entire survey, nor did they answer all the questions, which reduced the amount of useful data. Third, there were problems with the audio quality in some of the prerecorded videos in the EFT due to the wind interfering with the microphones during the field recording part. The noise, which interfered with the presenters' voice, could have made it difficult for subjects to understand certain parts of the EFT. However, this difficulty was present in less than 10 % of the materials. Fourth, there was the limitation of having only one presenter. Although the presenter had experience with outreach and scicomm, this may have led to audience fatigue. Finally, there was no detailed demographic assessment, which prevented us from distinguishing results between individuals from different backgrounds.

4 Results

The first pilot of the Rocks Really Rock program took place in April and May 2022. Forty-one teachers initially responded to the Google Form recruitment survey expressing interest in participating in the program. Six teachers and classrooms participated in the entire program, from EFT presentation to post-survey distribution and completion. Three classrooms were located in Florida, one classroom in New York City (homeschool), one classroom in North Dakota, and one classroom in Virginia. Six teachers answered the whole assessment as reported in Table 7. A total of 120 students participated in the EFT, and 120 surveys were completed via Qualtrics and paper copies, which were distributed by teachers after completion of the EFT to students who did not opt out of the program.

All the responses were downloaded from Qualtrics and coded as one data set for analysis in the SPSS software. Surveys with less than 90 % of complete responses were not used for the data analysis. A total of 83 usable student surveys were included in the data analysis. The survey responses are included as a spreadsheet in Supplement S2. Figure 3 shows the classroom–grade distribution of partici-

Table 3. Survey results about students' attitudes towards geology before and after an EFT. The table presents the mean score for two statements with the following ranking scale: 1: unexciting, mundane, unappealing /// 6: exciting, fascinating, appealing. N participants were surveyed, and N–t valid answers were taken into account to calculate the T-test value and its corresponding P value.

Statements BEFORE the "Rocks Really Rock" electronic field trip: I thought geology was	Mean score (standard deviation)	Statements AFTER the "Rocks Really Rock" electronic field trip: I now think geology is	Mean score (standard deviation)	N	T test before and after	P value (Sig. two-tailed)	N–t
unexciting exciting	2.99 (1.27)	unexciting exciting	3.72 (1.36)	83	−5.02	0.000	82
mundane fascinating	3.33 (1.35)	mundane fascinating	4.00 (1.36)	83	−5.08	0.000	82
unappealing appealing	3.23 (1.43)	unappealing appealing	4.01 (1.38)	83	−5.58	0.000	82

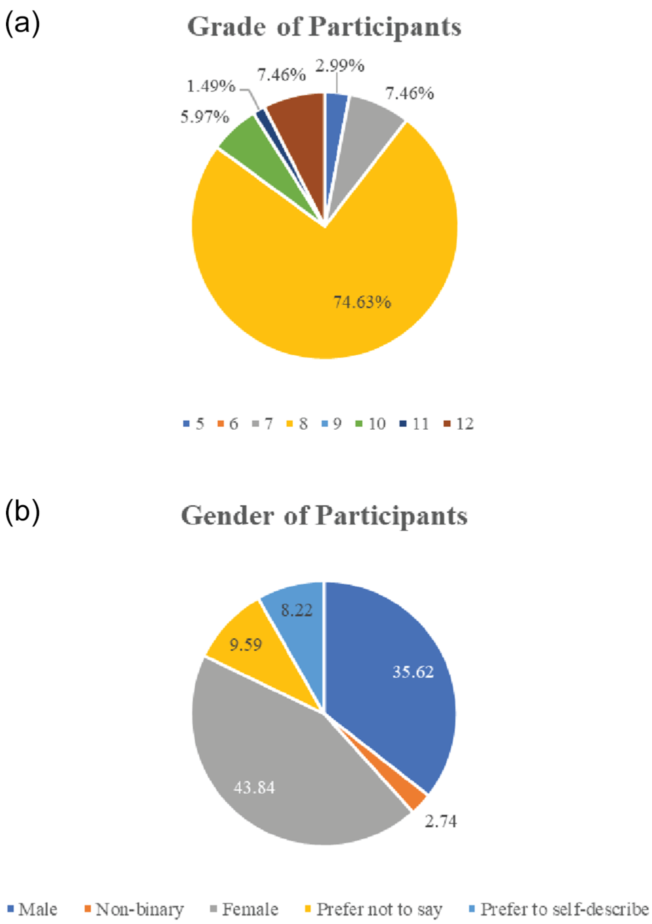

Figure 3. **(a)** Grade distribution from participant students. **(b)** Gender distribution from participant students.

pants who completed the post-survey, together with the gender distribution. Most of the participating students were female. The grade range was 5th–12th grade. All fifth-grade subjects were from the home-school participant class. As observed, most of the participants were middle-school students (sixth–eighth grade), and they made up 82 % of the sample.

4.1 Assessing EFT impact on students' attitudes toward geology

The first part of the survey attempted to determine how students' attitudes toward geology changed over the course of the EFT. Students were asked about their attitudes toward geology before and after the EFT on a scale of 1–6, where 1 was unexciting, mundane, and unappealing and 6 was exciting, fascinating, and appealing. Table 3 shows the means (M) for the responses to each of the statements for N valid responses and the standard deviation (SD) from each mean. The results of the paired t tests for the statements are reported for N–t valid responses. Overall, the results show a significant change in students toward more positive attitudes toward geology after the EFT, as indicated by t tests and p values < 0.05. The statement that showed the greatest (and most significant) change toward a more positive attitude was *Geology is appealing/unappealing* (t test: -5.58, $p = 0.00$). The statement that showed the least change toward a more positive attitude was *Geology is exciting/unexciting* (t test: -5.02, $p = 0.00$).

4.2 Assessing EFT impacts on students' attitudes toward geology careers

The second part of the survey attempted to determine how the students' attitudes toward geology careers changed due to their participation in the EFT. Students were asked about

Table 4. Survey results about students' attitudes about geology careers. The table presents the mean score for two statements with the following ranking scale: 1: strongly disagree, 2: somewhat disagree, 3: neither agree nor disagree, 4: somewhat agree, 5: strongly agree. N participants were surveyed, and N–t valid answers were considered to calculate the T-test value and its corresponding P value.

Statements	Mean score (standard deviation)		N	T before and after	P value (Sig. two-tailed)	N–t
	BEFORE participating in the Rocks Really Rock EFT, I thought	AFTER participating in the Rocks Really Rock EFT, I now think				
Geologists can work outdoors.	4.49 (0.79)	4.61 (0.71)	83	−1.32	0.19	82
Geology is a science.	4.26 (0.89)	4.49 (0.77)	82	−2.47	0.02	81
Geology is important.	3.71 (1.02)	4.23 (0.85)	83	−5.31	0.00	82
A job as a geologist would be interesting.	2.66 (1.07)	3.12 (1.14)	82	−3.93	0.00	81
I would consider geology as a major.	2.09 (1.06)	2.43 (1.17)	81	−3.64	0.00	80

their attitudes toward geology careers before and after the EFT via a post-retrospective survey using a five-point Likert scale with the following range: 1: strongly disagree, 2: somewhat disagree, 3: neither agree nor disagree, 4: somewhat agree, and 5: strongly agree. Table 4 shows the means (M) for the responses to each of the statements for N valid responses and the standard deviation (SD) from each mean. The results of the paired t tests for the statements are reported for N–t valid responses, which are the number of answers that can be paired and compared through the test. Statements 2, 3, and 4 showed a statistically significant change in perception, all having p values < 0.05. By contrast, the t test for statement 1 is not statistically significant according to the p value > 0.05. The statement that showed the greatest (and significant) change toward a more positive attitude was *Geology is important* (t test $= -5.31$, $p = 0.00$). The statement that showed the least change toward a more positive attitude was *Geology is a science* (t test $= -2.47$, $p = 0.02$).

4.3 Assessing the impact of the EFT on students' perceptions of geology literacy

The third part of the survey attempted to determine how the students' perceptions of geology literacy changed due to the EFT. Students were asked about their attitudes toward geology literacy before and after the EFT using a five-point Likert scale with the following range: 1: strongly disagree, 2: somewhat disagree, 3: neither agree nor disagree, 4: somewhat agree, 5: strongly agree. Table 5 shows the means (M) for the responses to each of the statements for "N" valid responses. The results of the paired t tests for the statements are reported for N–t valid responses. All the results showed a statistically significant positive change with p values < 0.05. The statement that showed the greatest change was *I have a great deal of knowledge about geology* ($t = -8.36$, $p = 0.00$).

In addition, students were asked about their knowledge of rocks before and after the EFT on a five-point Likert scale with the following range: 1: nothing, 2: not much, 3: a little, 4: a lot, and 5: everything. Table 6 shows the means (M) for the responses for one question for $N = 82$ valid responses. The mean score for the question *Before the electronic field trip, how much did you know about rocks?* was $M = 2.93$ (SD $= 0.80$), which is between "not much" and "a little", and the mean score for the question *After the electronic field trip, how much do you know about rocks?* was $M = 3.62$ (SD $= 0.75$), which is between "a little" and "a lot". The results of a paired t test for this statement, for N–t valid responses,

Table 5. Survey results about students' perceived literacy in geology Part 1. The table presents the mean score for two statements with the following ranking scale: 1: strongly disagree, 2: somewhat disagree, 3: neither agree nor disagree, 4: somewhat agree, 5: strongly agree. N participants were surveyed, and N–t valid answers were considered to calculate the T-test value and its corresponding P value.

Statements BEFORE participating in the Rocks Really Rock EFT, I thought	Mean score (standard deviation)	Statements AFTER the "Rocks Really Rock" electronic field trip, I now think geology is	Mean score (standard deviation)	N	T test before and after	P value (Sig. two-tailed)	N–t
I have a great deal of knowledge about geology.	2.66 (1.00)	I have a great deal of knowledge about geology.	3.46 (0.89)	83	−8.36	0.00	82
I would like to learn more about geology.	2.84 (1.07)	I would like to learn more about geology.	3.40 (1.20)	82	−5.54	0.00	81

Table 6. Survey results about students' attitudes about perceived literacy in geology before and after the EFT Part 2. The table presents the mean score for two statements with the following ranking scale: 1: nothing, 2: not much, 3: a little, 4: a lot, 5: everything. N participants were surveyed, and N–t valid answers were considered to calculate the T-test value and its corresponding P value.

	Mean score (standard deviation): students' attitudes	N
Before the electronic field trip, how much did you know about rocks?	2.92 (0.80)	82
After the electronic field trip, how much do you know about rocks?	3.62 (0.75)	82
T test	−9.53	
P value	0.00	
N–t	81	

showed a positive change in attitude with statistical significance.

4.4 Assessing teachers' perceptions of the EFT

The teachers' survey attempted to determine the teachers' perceptions of the EFT and to know their opinions about the program. Teachers were asked to evaluate their level of agreement or disagreement with 13 statements using a five-point Likert scale with the following range: 1: strongly disagree, 2: somewhat disagree, 3: neither agree nor disagree, 4: somewhat agree, 5: strongly agree. Table 7 shows the means (M) for the responses to each of the statements for N valid responses. The teachers' perceptions regarding the students' attitudes was the most positive regarding the statement *The scientist communicated at a level that I understood*. The lowest mean score reported by the teachers was regarding the statement *The virtual tour inspired my students to want to learn more about careers in geology*. In addition, one open question about opinions and possible improvements was included, and the answers are reported in Table 8.

5 Discussion

According to the Council of Advisors on Science and Technology of the President of the United States, there will be a shortage of nearly 1 million STEM professionals in the coming years. Their projections show that STEM fields will need to increase their recruitment by 34 % (Crawford et al., 2021; Olson and Riordan, 2012). As noted previously, this situation may be more challenging for ES careers given the lack of exposure or awareness of ES disciplines among K-12 students, in addition to the low ES literacy of the general population. For this reason, given that high-quality education in K-12 school settings has the potential to reinforce positive attitudes toward STEM content and careers, the role of these environments is very important in building an ES-literate society and increasing ES career awareness (Locke et al., 2018). Furthermore, science educators can effectively support these formal educational settings through outreach activities, which have the potential to increase students' positive attitudes toward STEM and related careers and increase the motivation to engage in STEM activities (Vennix et al., 2017, 2018).

The purpose of this study was to determine the impact of an EFT in Web Google Earth on ES topics for K-12 students. To do so, we built a Web Google Earth EFT using prerecorded videos called Rocks Really Rock: An Electronic Field Trip across Geological Time and assessed it with students from seven middle and high schools in the United States. Our results showed that EFTs in ES are effective tools that can be created by Earth scientists to develop outreach projects and support K-12 science educators in (1) generating positive at-

Table 7. Survey results about teachers' perceptions of the EFT. Scale: 1: strongly disagree, 2: somewhat disagree, 3: neither agree nor disagree, 4: somewhat agree, 5: strongly agree.

Statements	Mean score (standard deviation)	*N*
The topic was interesting.	4.83 (0.41)	6
The scientist was interesting.	4.83 (0.41)	6
The scientist talked about something I did not already know.	4.33 (0.82)	6
The scientist communicated at a level that I understood.	5	6
The scientist was knowledgeable about the topic.	4.83 (0.41)	6
The scientist gave an interesting demonstration to explain the origin of rocks.	4.33 (1.21)	6
It is important that we learn about Earth's history.	4.83 (0.41)	6
I learned about careers in geology from the scientist.	4.17 (0.75)	6
I would recommend this electronic field trip to other classes.	4.66 (0.52)	6
My students were engaged with the virtual tour.	3.83 (0.98)	6
The virtual tour inspired my students to ask questions about geology.	3.83 (0.41)	6
The virtual tour inspired my students to want to learn more about careers in geology.	3.17 (0.75)	6
The electronic field trip was easy to hear.	4.33 (1.21)	6

titudes toward the ES, (2) positively impacting interest in ES careers, and (3) reinforcing positive perceptions in ES literacy. In the following section we present our considerations of this type of EFT and discuss the findings in relation to our research objectives.

5.1 Changes in students' attitudes towards Earth sciences using EFT

The results of this study, in light of the existing literature on STEM and ES outreach, support the following factors that we believe determine a positive change in K-12 students' attitudes toward ES using EFTs: (1) the use of prerecorded videos in the Web Google Earth platform; (2) the two-way asynchronous interactions between teacher, student, and scientist; and (3) the use of storytelling to design the content of the EFT. Here, we lay out the main considerations that led us to propose these factors.

5.1.1 Use of prerecorded videos in Web Google Earth

There are several advantages (for both creators and users) of Web Google Earth as a platform for creating virtual field trips in the ES, such as the effective and user-friendly format and interface of the platform, the easy way to distribute via the direct web link, the ability to geotag the different field trip stops in one single project, or the 3D view navigation of the locations providing opportunities for independent exploration (Barth et al., 2022; Evelpidou et al., 2021; Mahan et al., 2021; Wyatt and Werner, 2019). In addition, EFTs through Web Google Earth do not limit the experience to the geotagged locations but also allow the creator to include links to supporting materials (e.g., links to publications, maps, or

Table 8. Survey results about teachers' opinions of the EFT.

Respondent	Survey indication: Please leave a comment about what went well and didn't go well by using the EFT. If you have any suggestions for improving the program, write them below.
1	"It is best to share the EFT as whole class. Using ipads or chromebooks has issues with school wifi. It would be neat to have a live virtual EFT."
2	"They EFT went well because we could complete it at our pace. I could go to the places on the map that my students wanted to look at."
3	"I enjoyed the multiple sites. The camera and mic quality were great. The conversation was a little stiff and could use a second scientist to conversate with."
4	"No problems with using the link or the videos. The sound quality when outdoors was sometimes a little difficult to hear/understand due to the wind. The indoor recording had echo. I presented the EFT on a SmartBoard so all students could watch. [...]"
5	"The students liked seeing the rocks in their natural habitat. When we visit again, I will create a work sheet for the students to take notes during the presentation and another to sum up what they have learned. A link to more information would be helpful too. Some of the students commented that the volume changed and that you could hear the wind. A fluffy microphone might help with that. Overall, we liked the trip and I plan on using it again in the future."
6	"Using EFT was very easy and instructions were clear in how to navigate through it and what to do to prepare and send opt-out options for parents. Some of the information was hard to hear with the way some of the videos were recorded."

field guides) and display multimedia content (photos, videos, satellite images, slides) that allow the user to further explore the studied area (Evelpidou et al., 2021).

One of the more powerful outreach benefits of Web Google Earth is the use of multimedia, particularly video. Several studies have shown that multimedia in both science education and outreach can present science materials effectively, efficiently, and more interestingly, which helps students engage with science content and achieve learning outcomes (Morris and Lambe, 2017; Syawaludin et al., 2019; Wang et al., 2022). For example, prerecorded videos in ES are known to increase interest in STEM because they provide a way to present content knowledge to the public using images, text, multimedia, etc., which can also create a different pedagogical experience (Wang et al., 2022). We suggest that ES outreach programs through Web Google Earth can benefit from the possibility of combining two tools: prerecorded ES videos and geotagged locations. This allows students to follow the presenter's explanations, experience the presenter's field observations at each site, and explore the geotagged locations where the videos were filmed. The prerecorded videos also allowed us to embed explanatory graphics and videos from other creators. Our videos can easily be found by other ES educators on YouTube and can be used in various teaching and learning environments as accessible support materials for other ES educators around the world (Maynard, 2021; Welbourne and Grant, 2016).

5.1.2 Asynchronous interactions between teacher, student, and scientist

The benefits of interactions between students, teachers, and scientists have been previously evaluated and found to be an essential part of science outreach by positively changing students' perceptions of science and science-related careers (Barry et al., 2022; Painter et al., 2006; Rogers et al., 2024). International science organizations, researchers, and K-12 science educators across the globe believe that there is a need for scientists to be involved in science education (GSA Position Statement, 2013; King, 2013; Levine et al., 2007). Currently, several ES K-12 outreach strategies for students and teachers focus on in-person visits from professional scientists, visits to science fairs, visits to science museums, and field trips (Abramowitz et al., 2021; Onstad, 2021; Tillinghast et al., 2019). However, many of these outreach strategies have limitations, including lack of funding for in-person visits, time-consuming transportation, or accessibility.

Our results showed that outreach through EFTs in Web Google Earth is an asynchronous alternative for interactive learning experiences in formal educational environments (K-12 classrooms). This mode of EFT has the potential to create positive attitudes toward ES and ES careers, similar to previous synchronous interactions through EFTs via the Streaming Science model (Barry et al., 2022; Loizzo et al., 2019). Because the core of the EFT activity is asynchronous, it has the advantage of being used multiple times by students and teachers after the class activity, and it allows the teacher to view it prior to the class activity. This is also supported by one of the responses to the teachers' survey: "The EFT went well because we could complete it at our pace. I could go to the places on the map that my students wanted to look at". Additionally, the asynchronous, prerecorded nature of the EFT reduces barriers for students and teachers, who may face barriers to accessing field-based outreach events due to financial limitations or physical disabilities (among others), allowing for inclusive participation in outreach activities.

5.1.3 The use of storytelling to craft the content of the EFT

Several studies have highlighted that ES is a challenging set of sciences to communicate to non-expert audiences (Scherer et al., 2017; Sell et al., 2006). Wang et al. (2022) proposed three categories to explain the challenges of communicating ES topics: (1) Earth processes operate at unobservable locations and nonhuman "deep timescales", (2) ES information is more relevant to some locations than others, and (3) ES topics involve complex and dynamic systems. Therefore, regardless of the accuracy of the content of an ES outreach strategy, it may not always be effective in positively impacting the learning experience of non-expert audiences or in engaging them with scientific content. However, there are several science communication tools that geoscientists can use to effectively communicate ES to the public, such as science storytelling (McNeal et al., 2014; Stewart and Hurth, 2021), and within storytelling there are several tools that may help science stories to engage the target audience, such as the ABT structure (Olson, 2015).

Our research supports previous research that suggests that science communication through storytelling is an effective strategy for achieving positive impacts through ES outreach initiatives (Dahlstrom, 2014; Joubert et al., 2019; Martinez-Conde and Macknik, 2017; Rogers et al., 2024). In this study, the presenter used a storytelling approach using a chronological narrative to present facts and evidence about Earth's history, allowing students to go through the science content as if they were being told the story of Earth through time. In addition, applying the ABT structure to showcase geology careers provided a framework to justify the role of geologists in understanding the history of Earth. Our results show overall that the content of our prerecorded videos was effective in promoting interest in ES and ES careers, suggesting that storytelling may contribute significantly when developing asynchronous science outreach material for K-12 students.

5.2 Addressing the challenges in ES education and ES careers through outreach

The study discussed in this article focused on the evaluation of attitudes toward geology and ES education using an EFT intervention. The results of *t* tests indicated a statistically significant positive change in attitudes toward geology, suggesting that participating in the EFT increased students' positive attitudes toward ES. These findings demonstrate the potential to expand EFT to other ES fields and to reach middle- and high-school students. These findings align with previous research on STEM education and outreach, emphasizing the significance of positive attitudes and well-informed perceptions in fostering interest in ES learning and pursuit of ES careers. In the following section we discuss the following topics: (1) the role of EFTs in students' attitudes toward Earth sciences and (2) the role of EFTs in Earth sciences in the perception of ES literacy.

5.2.1 The role of EFTs in students' attitudes toward Earth sciences

The *t* tests done for the statements regarding attitudes toward geology (e.g., *Geology is unexciting/exciting, Geology is mundane/fascinating*, or *Geology is appealing/unappealing*) showed a statistically significant positive change, indicating that attitudes toward ES increased after students participated in an EFT. These findings demonstrate the feasibility of expanding EFTs to other ES fields (not just geology) and to middle- and high-school (and home) students. Thus, EFTs may help science educators change negative or neutral attitudes toward ES to positive attitudes. In addition, EFTs may address teacher unpreparedness for ES content and the paucity of available interactive ES instructional resources that prevent and limit ES instruction in various K-12 settings (King, 2013).

Based on our findings, the lack of awareness of ES may not be as much of a challenge for ES education (as reported in the literature) as the lack of enthusiasm for ES among K-12 students. Our results showed that there was no statistically significant change when we measured awareness, as most students were aware of geology as a science and where geologists might work before the EFT. However, the *t* tests related to the statements measuring attitudes toward geology and geology careers all showed significant positive results.

Research has shown that students considering geology careers do so as early as middle school (Lyon et al., 2020). Thus, the use of EFTs in this stage can become a powerful intervention strategy to influence ES career choices in a positive way. Based on our findings, there was a significant positive change after following the EFT in attitudinal statements about geology careers in both the students' and teachers' surveys (e.g., *A job as a geologist would be interesting, I would consider geology as a major, geology is important* or *The virtual tour inspired my students to want to learn more about careers in geology*). Therefore, such EFTs can combine K-12 ES topics (linking learning goals to ESLPs or NGSS) with real-world career scenarios to increase students' interest in ES careers. These EFTs can address students' difficulties connecting science content to career pathways as well as educators' lack of knowledge about realistic role models in these careers (Jahn and Myers, 2015; Levine et al., 2007; Lyon et al., 2020; McNeal et al., 2014; Petcovic et al., 2018). We recognize that the implementation of this EFT in the science classroom did not necessarily indicate successful recruitment of students to an ES major, but the data demonstrated that the EFT was successful in positively impacting students' thoughts about choosing a geology major.

All the findings discussed in this article support previous STEM education and outreach research in ES and other STEM fields. Prior research has shown that an EFT as an outreach strategy can support STEM education by fostering positive attitudes toward science, which tends to encourage the youth to pursue STEM careers and build a skilled STEM workforce (Barry et al., 2022; Loizzo et al., 2019). Similarly, several studies in ES education remind us that positive attitudes and well-informed perceptions about the field of geology and other ES fields influence middle- and high-school students' interest in ES learning and desire to pursue ES careers (Kurtis, 2009; Lyon et al., 2020; McNeal et al., 2014).

5.2.2 The role of EFTs in Earth sciences in the perception of ES literacy

Our study found that an EFT built in Web Google Earth covering ES topics had a positive impact on students' perceptions of geology literacy and their interest in learning geology topics. After students completed the retrospective self-assessment of their knowledge of ES, there was a statistically significant positive difference in the pre and post statements. The change in the statement *I have a great deal of knowledge about geology* indicated that the EFT had a positive impact on the students' perception of their knowledge of ES and that this perception improved. Similarly, the change in the statement *I would like to learn more about geology* showed that students had an increased desire to learn and an increased interest in geology after the EFT.

Our study contrasts with other studies that have assessed students' perceptions and interest in ES literacy by exposing K-12 students to ES content but that have not necessarily obtained positive attitudinal changes after the programs. For example, Lyon et al. (2020) used the statement *I would like to learn more about geology* in an attitudinal survey program for ninth graders who had been exposed to a geosciences course with content aligned with the NGSS. Their data showed a decrease in interest in geology in the post-survey after the course had been taken. The authors considered that one of the main challenges may have been in "translating material covered in class into something they (the students) value" (Lyon et al., 2020). The difference in results between an ES course and an ES outreach program such as our EFT supports our previously mentioned premise about how ES topics are communicated (using storytelling and multimedia) and supports the idea that, in K-12 settings, ES outreach using multimedia and science communication tools may be more effective in generating positive attitudes toward geology than exposing students to ES courses.

Although our study focused on the US education system, several challenges of ES education and careers are shared by several other countries, as mentioned above. Thus, this strategy has the potential to be implemented globally, to complement or cover gaps in the ES curriculum at the primary and secondary levels, and to work towards improving awareness of ES careers (King et al., 2021). For example, in countries such as Chile, researchers have found that the ES K-12 school curriculum is not relevant and have therefore called for the implementation of educational experiences related to ES (Villaseñor et al., 2020), for which EFTs may also work.

5.3 Recommendations: how can the implementation of Earth science electronic field trips be improved?

Based on this pilot study using Web Google Earth for ES outreach in K-12 environments, we consider a number of recommendations for EFT creators, users, and further research. Creators, especially scientists with no experience in multimedia creation, may find it useful to allocate funding to work with expert multimedia editors to fund the participation of other subject matter experts during the video recordings and to integrate dialog and conversation among the presenters, as noted by one of the responses to the teachers' survey. Funding may also be allocated to improve the video and audio quality of the delivered content. In addition, more content can be added to each site between longer-form videos if there is an opportunity to explore more sites in the area. By making more content available at multiple geotagged locations, students and teachers will be able to engage with the application in a more interactive way.

The EFT is adaptable to many ways of class instruction, whether this is more individual- or group-focused. We suggest that the teachers first go through the Web Google Earth program on their own before presenting it in their classrooms and, if deemed appropriate, design exercises using the concepts learned in the EFT that can complement the activity before, during, or after the EFT are presented to students, similarly to this teacher's idea: "When we visit again, I will create a work sheet for the students to take notes during the presentation and another to sum up what they have learned." Teachers can also network with the creators and participate in annual research to assess the impact of these EFTs at different K-12 levels to determine which groups of students are more or less impacted. These strategies, altogether, may potentially reduce the impact of our previously identified limitations to the outreach program, such as the technical difficulties of recording videos in the outdoors, or the audience fatigue that may be caused by single-presenter videos, both included in the recommendations teachers gave to this first pilot program (Table 8).

6 Conclusions

Earth sciences are relevant to society and its relationship with the Earth system. However, ES education in US K-12 environments faces multiple challenges, such as (1) limited exposure to ES, (2) lack of awareness of ES careers, and (3) low ES literacy. Interactions between science educators, students, and scientists are an essential part of science outreach. Previous studies have shown that successful outreach programs leading to positive attitudinal changes toward STEM in students can help students understand how science can explain the natural world around them.

This study found that outreach through EFTs in Web Google Earth is an asynchronous alternative to synchronous interactive learning experiences in formal education environments (K-12 classrooms). Our study showed that Web Google Earth EFTs have the potential to increase positive attitudes toward ES (specifically geology), interest in ES careers, and perceptions of ES literacy, providing several advantages for ES K-12 outreach. The use of EFTs for ES outreach presents a unique opportunity for Earth scientists located not only in the United States, but anywhere on the globe, to network with K-12 educators and address these challenges, creating interactions between scientists and K-12 classrooms. Our findings indicated that one of the major problems in ES education is not a lack of awareness, but a lack of excitement among K-12 students about ES topics, and therefore scicomm tools such as storytelling and use of multimedia in platforms such as Web Google Earth provide an effective strategy for creating outreach content that generates engagement with science topics and increases positive attitudes toward science.

Data availability. The authors confirm that the data supporting the findings of this study are available within the article and its Supplement.

Video supplement. The following link contains the public web address to the electronic field trip "Rocks Really Rock", which takes viewers to the Web Google Earth application at https://earth.google.com/earth/d/1btfkYpOkcsqQktfky-t0pYJLT1e2lJSP?usp=sharing (Ortiz-Guerrero, 2024).

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Ethical statement. The data used in this study were collected on a voluntary and anonymous basis. Identification of individual participants in the questionnaire is impossible. Ethics approval was obtained through the University of Florida's Institutional Review Board (IRB).

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References

Abramowitz, B., Ennes, M., Killingsworth, S., Antonenko, P. D., MacFadden, B., and Ivory, A.: Science in School: Transforming K-12 Outreach Through Scientist Teacher Partnerships, Journal of STEM Outreach, 4, 1–14, https://doi.org/10.15695/jstem/v4i1.14, 2021.

Adedokun, O., Parker, L. C., Loizzo, J., Burgess, W., and and Robinson, J. P.: A field trip without buses: Connecting your students to scientists through a virtual visit, Science Scope, 34, 52–57, 2011.

Adetunji, O. O., Ba, J.-C. M., Ghebreab, W., Joseph, J. F., Mayer, L. P., and Levine, R.: Geosciences Awareness Program: A Program for Broadening Participation of Students in Geosciences, Journal of Geoscience Education, 60, 234–240, https://doi.org/10.5408/10-208.1, 2012.

Aenlle, J. V., Loizzo, J., Bunch, J. C., Stone, W., Meredith, M., and Ray, K.: Conservation conversation: An arts-based approach to examine impacts of a live video webcast on youth viewers' conceptualizations of forest ecosystems, Applied Environmental Education and Communication, 21, 221–237, https://doi.org/10.1080/1533015X.2022.2034554, 2022.

Arcand, K. and Watzke, M.: Bringing the universe to the street. A preliminary look at informal learning implications for a large-scale non-traditional science outreach project, Journal of Science Communication, 9, A01, https://doi.org/10.22323/2.09020201, 2010.

Barry, S., Stofer, K. A., Loizzo, J., and DiGennaro, P.: High school students' perceptions of science and scientists improve following university-based online DNA day, J. Biol. Educ., 57, , 1170–1185, https://doi.org/10.1080/00219266.2021.2012228, 2022.

Barth, N. C., Stock, G. M., and Atit, K.: From a virtual field trip to geologically reasoned decisions in Yosemite Valley, Geosci. Commun., 5, 17–28, https://doi.org/10.5194/gc-5-17-2022, 2022.

Beattie, P. N., Loizzo, J., Kent, K., Krebs, C. L., Suits, T., and Bunch, J. C.: Leveraging Skype in the Classroom for Science Communication: A Streaming Science – Scientist Online Approach, Journal of Applied Communications, 104, 9, https://doi.org/10.4148/1051-0834.2328, 2020.

Bond, C. E., Pugsley, J. H., Kedar, L., Ledingham, S. R., Skupinska, M. Z., Gluzinski, T. K., and Boath, M. L.: Learning outcomes, learning support, and cohort cohesion on a virtual field trip: an analysis of student and staff perceptions, Geosci. Commun., 5, 307–323, https://doi.org/10.5194/gc-5-307-2022, 2022.

Brown, S. V. and Clewell, B. C.: Project talent flow: The non-SEM field choices of Black and Latino undergraduates with the aptitude for science, engineering and mathematics careers, Report Presented to the Alfred P. Sloan Foundation, 1998.

Burns, T. W., O'Connor, D. J., and Stocklmayer, S. M.: Science Communication: A Contemporary Definition, Public Underst. Sci., 12, 183–202, https://doi.org/10.1177/09636625030122004, 2003.

Carabajal, I. G., Marshall, A. M., and Atchison, C. L.: A Synthesis of Instructional Strategies in Geoscience Education Literature That Address Barriers to Inclusion for Students With Disabilities, Journal of Geoscience Education, 65, 531–541, https://doi.org/10.5408/16-211.1, 2017.

Cassady, J. and Kozlowski, A.: Electronic Field Trips as Interactive Learning Events: Promoting Student Learning at a Distance, Journal of Interactive Learning Research, 19, 439–454, 2023, 2008.

Choi, Y.-S., Choe, S.-U., and Kim, C.-J.: Examining Middle School Students' Gestures on Geological Field Trips, Asia-Pacific Science Education, 6, 97–115, https://doi.org/10.1163/23641177-BJA10002, 2020.

Clary, R. M.: Can the history of geology inform geoscience education and public reception of climate change? Lessons from the history of glacial theory, Geosphere, 14, 642–650, https://doi.org/10.1130/GES01461.1, 2018.

Cliffe, A. D.: A review of the benefits and drawbacks to virtual field guides in today's Geoscience higher education environment, International Journal of Educational Technology in Higher Education, 14, 28, https://doi.org/10.1186/s41239-017-0066-x, 2017.

Crawford, A. J., Hays, C. L., Schlichte, S. L., Greer, S. E., Mallard, H. J., Singh, R. M., Clarke, M. A., and Schiller, A. M.: Retrospective analysis of a STEM outreach event reveals positive influences on student attitudes toward STEM careers but not scientific methodology, Adv. Physiol. Educ., 45, 427–436, https://doi.org/10.1152/advan.00118.2020, 2021.

Dahlstrom, M. F.: Using narratives and storytelling to communicate science with nonexpert audiences, P. Natl. Acad. Sci. USA, 111, 13614–13620, https://doi.org/10.1073/pnas.1320645111, 2014.

Dawborn-Gundlach, L. M., Pesina, J., Rochette, E., Hubber, P., Gaff, P., Henry, D., Gibson, M., Kelly, L., and Redman, C.: Enhancing pre-service teachers' concept of Earth Science through an immersive, conceptual museum learning program (Reconceptualising Rocks), Teach. Teach. Educ., 67, 214–226, https://doi.org/10.1016/j.tate.2017.06.012, 2017.

Dolphin, G., Dutchak, A., Karchewski, B., and Cooper, J.: Virtual field experiences in introductory geology: Addressing a capacity problem, but finding a pedagogical one, Journal of Geoscience Education, 67, 114–130, https://doi.org/10.1080/10899995.2018.1547034, 2019.

Evelpidou, N., Karkani, A., Saitis, G., and Spyrou, E.: Virtual field trips as a tool for indirect geomorphological experience: a case study from the southeastern part of the Gulf of Corinth, Greece, Geosci. Commun., 4, 351–360, https://doi.org/10.5194/gc-4-351-2021, 2021.

Fitzakerley, J. L., Michlin, M. L., Paton, J., and Dubinsky, J. M.: Neuroscientists' Classroom Visits Positively Impact Student Attitudes, PLoS ONE, 8, e84035, https://doi.org/10.1371/journal.pone.0084035, 2013.

Gates, A. E. and Kalczynski, M. J.: The Oil Game: Generating Enthusiasm for Geosciences in Urban Youth in Newark, NJ, Journal of Geoscience Education, 64, 17–23, https://doi.org/10.5408/10-164.1, 2016.

Geoscience on the chopping block, Nat. Rev. Earth. Environ., 2, 587, https://doi.org/10.1038/s43017-021-00216-1, 2021.

GSA Position Statement: Promoting Earth Science Literacy for Public Decision Making, https://www.geosociety.org/gsa/positions/position21.aspx, last access: 1 March 2024, 2013.

Gonzales, L. and Keane, C.: Status of the Geoscience Workforce 2011, The American Geological Institute Workforce Program, ISBN 978-0-922152-86-5, 2011.

Granshaw, F. D. and Duggan-Haas, D.: Virtual fieldwork in geoscience teacher education: Issues, techniques, and models, edited by: Whitmeyer, S. J., Bailey, J. E., De Paor, D. G., and Ornduff, T., Google Earth and Virtual Visualizations in Geoscience Education and Research, Geological Society of America, https://doi.org/10.1130/2012.2492(20), 2012.

Gürer, D., Hubbard, J., and Bohon, W.: Science on social media, Commun. Earth Environ., 4, 148, https://doi.org/10.1038/s43247-023-00810-9, 2023.

Hanks, C., Levine, R., Gonzalez, R., Wartes, D., and Fowell, S.: Survey Development for Measuring the Near-term Effectiveness of a Program to Recruit Minority Geoscientists, Journal of Geoscience Education, 55, 244–250, https://doi.org/10.5408/1089-9995-55.3.244, 2007.

Harrison, M., Baldwin, S., Caffee, M., Gehrels, G., Schoene, B., Shuster, D., and Singer, B.: Geochronology: It's about time, Eos, 96, https://doi.org/10.1029/2015EO041901, 2015.

Hildenbrand, G. M.: Explaining jargon using clear communication strategies, Communication Teacher, 36, 10–13, https://doi.org/10.1080/17404622.2021.1906924, 2022.

Hoisch, T. D. and Bowie, J. I.: Assessing Factors that Influence the Recruitment of Majors from Introductory Geology Classes at

Northern Arizona University, Journal of Geoscience Education, 58, 166–176, https://doi.org/10.5408/1.3544297, 2010.

Jahn, J. L. S. and Myers, K. K.: "When Will I Use This?" How Math and Science Classes Communicate Impressions of STEM Careers: Implications for Vocational Anticipatory Socialization, Communication Studies, 66, 218–237, https://doi.org/10.1080/10510974.2014.990047, 2015.

Jeffers, A., Safferman, A., and Safferman, S.: Understanding K–12 engineering outreach programs, J. Prof. Iss. Eng. Ed. Pr., 130, 95–108, https://doi.org/10.1061/(ASCE)1052-3928(2004)130:2(95), 2004.

Joubert, M., Davis, L., and Metcalfe, J.: Storytelling: The soul of science communication, Journal of Science Communication, 18, https://doi.org/10.22323/2.18050501, 2019.

King, C.: Geoscience education across the globe – results of the IUGS-COGE/IGEO survey, Episodes, 36, 19–30, https://doi.org/10.18814/epiiugs/2013/v36i1/004, 2013.

King, C., Gorfinkiel, D., and Frick, M.: International comparisons of school-level geoscience education–the UNESCO/IGEO expert opinion survey, Int. J. Sci. Educ., 43, 56–78, https://doi.org/10.1080/09500693.2020.1854894, 2021.

Kurtis, K.: Minority college student attitudes toward the geological sciences: Unearthing barriers to enrollment, thesis, California State University, Long Beach, United States, 2009.

LaDue, N. D. and Clark, S. K.: Educator Perspectives on Earth System Science Literacy: Challenges and Priorities, Journal of Geoscience Education, 60, 372–383, https://doi.org/10.5408/11-253.1, 2012.

Levine, R., González, R., Cole, S., Fuhrman, M., and Le Floch, K. C.: The Geoscience Pipeline: A Conceptual Framework, Journal of Geoscience Education, 55, 458–468, https://doi.org/10.5408/1089-9995-55.6.458, 2007.

Locke, S. L., Bracey, G., Foster, T., Fraine, S., Hu, S., Lacombe, K., and Wilson, C.: Connecting formal and informal learning to enhance elementary teacher preparation in geosciences, Terrae Didatica, 14, 282–288, https://doi.org/10.20396/td.v14i3.8653527, 2018.

Loizzo, J., Harner, M. J., Weitzenkamp, D. J., and Kent, K.: Electronic Field Trips for Science Engagement: The Streaming Science Model, Journal of Applied Communications, 103, 2, https://doi.org/10.4148/1051-0834.2275, 2019.

Lyon, E., Freeman, R. L., Bathon, J., Fryar, A., McGlue, M., Erhardt, A. M., Rosen, A., Sampson, S., Nelson, A., and Parsons, J.: Attitudinal impediments to geology major recruitment among ninth graders at a STEM high school, Journal of Geoscience Education, 68, 237–253, https://doi.org/10.1080/10899995.2019.1700593, 2020.

Mahan, K. H., Frothingham, M. G., and Alexander, E.: Virtual mapping and analytical data integration: a teaching module using Precambrian crystalline basement in Colorado's Front Range (USA), Geosci. Commun., 4, 421–435, https://doi.org/10.5194/gc-4-421-2021, 2021.

Maltese, A. V. and Tai, R. H.: Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students, Sci. Educ., 95, 877–907, https://doi.org/10.1002/sce.20441, 2011.

Martinez-Conde, S. and Macknik, S. L.: Finding the plot in science storytelling in hopes of enhancing science communication, P. Natl. Acad. Sci. USA, 114, 8127–8129, https://doi.org/10.1073/pnas.1711790114, 2017.

Maynard, A. D.: How to Succeed as an Academic on YouTube, Front. Commun., 5, 572181, https://doi.org/10.3389/fcomm.2020.572181, 2021.

McNeal, K. S., Spry, J. M., Mitra, R., and Tipton, J. L.: Measuring Student Engagement, Knowledge, and Perceptions of Climate Change in an Introductory Environmental Geology Course, Journal of Geoscience Education, 62, 655–667, https://doi.org/10.5408/13-111.1, 2014.

Morris, N. P. and Lambe, J.: Multimedia interactive eBooks in laboratory bioscience education, Higher Education Pedagogies, 2, 28–42, https://doi.org/10.1080/23752696.2017.1338531, 2017.

National Research Council of the National Academies: A framework for K-12 science education: Practices, crosscutting concepts, and core ideas, National Academies Press, United States of America, ISBN 13:978-0-309-21742-2, 2012.

National Research Council: Next generation science standards: For states by states, The National Academies Press, United States of America, https://doi.org/10.17226/18290, 2013.

OECD: Programme for International Student Assessment, and Organisation for Economic Co-operation and Development (Eds.), PISA 2018 Results, OECD, https://doi.org/10.1787/5f07c754-en, 2019.

Olson, R.: Houston, we have a narrative: Why science needs story, University of Chicago Press, 2015.

Olson, S. and Riordan, D. G.: Engage to excel: producing one million additional college graduates with degrees in science, technology, engineering, and mathematics, Report to the president, Executive office of the president, 2012.

Onstad, C.: Earth Science Education #6. Lessons Learned: Organizing a Geoscience Outreach Program at the University of Saskatchewan, Geosci. Can., 48, 133–139, https://doi.org/10.12789/geocanj.2021.48.178, 2021.

Ortiz-Guerrero, C.: A Virtual Field Trip through Geologic Time, https://earth.google.com/earth/d/1btfkYpOkcsqQktfky-t0pYJLT1e2lJSP?usp=sharing, last access: 22 April 2024.

Osborne, J., Simon, S., and Collins, S.: Attitudes towards science: A review of the literature and its implications, Int. J. Sci. Educ., 25, 1049–1079, https://doi.org/10.1080/0950069032000032199, 2003.

Painter, J., Jones, M. G., Tretter, T. R., and Kubasko, D.: Pulling Back the Curtain: Uncovering and Changing Students' Perceptions of Scientists, School Science and Mathematics, 106, 181–190, https://doi.org/10.1111/j.1949-8594.2006.tb18074.x, 2006.

Petcovic, H. L., Cervenec, J., Cheek, K., Dahl, R., and Price, N.: Research on Elementary, Middle, and Secondary Earth and Space Sciences Teacher Education, Community Framework for Geoscience Education Research, National Association of Geoscience Teachers, https://doi.org/10.25885/ger_framework/4, 2018.

Pugsley, J. H., Howell, J. A., Hartley, A., Buckley, S. J., Brackenridge, R., Schofield, N., Maxwell, G., Chmielewska, M., Ringdal, K., Naumann, N., and Vanbiervliet, J.: Virtual field trips utilizing virtual outcrop: construction, delivery and implications for the future, Geosci. Commun., 5, 227–249, https://doi.org/10.5194/gc-5-227-2022, 2022.

Pyle, E. J., Darling, A., Kreager, Z., and Conrad, S. H.: Research on Students' Conceptual Understanding of Geology/Solid Earth Science Content, James Madison University, https://doi.org/10.25885/GER_FRAMEWORK/2, 2018.

Roca, N. and Garcia-Valles, M.: Trainee Teacher Experience in Geoscience Education: Can We Do Better?, Geoheritage, 12, 92, https://doi.org/10.1007/s12371-020-00518-8, 2020.

Rogers, S. L., Giles, S., Dowey, N. J., Greene, S. E., Bhatia, R., Van Landeghem, K., and King, C.: "you just look at rocks, and have beards" Perceptions of geology from the UK: a qualitative analysis from an online survey, Earth Science, Systems and Society, in press, 2024.

Scherer, H. H., Holder, L., and Herbert, B.: Student Learning of Complex Earth Systems: Conceptual Frameworks of Earth Systems and Instructional Design, Journal of Geoscience Education, 65, 473–489, https://doi.org/10.5408/16-208.1, 2017.

Schmidt, K. and Kelter, P.: Science Fairs: A Qualitative Study of Their Impact on Student Science Inquiry Learning and Attitudes toward STEM, Science Educator, 25, 26–132, 2017.

Sell, K. S., Herbert, B. E., Stuessy, C. L., and Schielack, J.: Supporting Student Conceptual Model Development of Complex Earth Systems Through the Use of Multiple Representations and Inquiry, Journal of Geoscience Education, 54, 396–407, https://doi.org/10.5408/1089-9995-54.3.396, 2006.

Sherman-Morris, K., Brown, M. E., Dyer, J. L., McNeal, K. S., and Rodgers, J. C.: Teachers' Geoscience Career Knowledge and Implications for Enhancing Diversity in the Geosciences, Journal of Geoscience Education, 61, 326–333, 2013.

St. John, K., McNeal, K. S., MacDonald, R. H., Kastens, K. A., Bitting, K. S., Cervato, C., McDaris, J. R., Petcovic, H. L., Pyle, E. J., Riggs, E. M., Ryker, K., Semken, S., and Teasdale, R.: A community framework for geoscience education research: Summary and recommendations for future research priorities, Journal of Geoscience Education, 69, 2–13, https://doi.org/10.1080/10899995.2020.1779569, 2021.

Stewart, I. S. and Hurth, V.: Selling planet Earth: Re-purposing geoscience communications, Geological Society, London, Special Publications, 508, 265–283, https://doi.org/10.1144/SP508-2020-101, 2021.

Stocklmayer, S.: Public awareness of science and informal learning: a perspective on the role of science museums, The Informal Learning Review, 72, 14–19, 2005.

Syawaludin, A., Gunarhadi, G., and Rintayati, P.: Development of Augmented Reality-Based Interactive Multimedia to Improve Critical Thinking Skills in Science Learning, International Journal of Instruction, 12, 331–344, https://doi.org/10.29333/iji.2019.12421a, 2019.

Tai, R. H., Qi Liu, C., Maltese, A. V., and Fan, X.: Planning Early for Careers in Science, Science, 312, 1143–1144, https://doi.org/10.1126/science.1128690, 2006.

Tillinghast, R. C., Petersen, E. A., Kroth, W., Powers, G., Holzer, M., Osowski, J., and Mansouri, M.: Bringing Geosciences to K-12 Classrooms: A Teacher Training Program Developed by the Sterling Hill Mining Museum, 2019 IEEE Integrated STEM Education Conference (ISEC), Princeton, NJ, USA, 69–75, https://doi.org/10.1109/ISECon.2019.8882052, 2019.

Vennix, J., den Brok, P., and Taconis, R.: Perceptions of STEM-based outreach learning activities in secondary education, Learning Environments Research, 20, 21–46, https://doi.org/10.1007/s10984-016-9217-6, 2017.

Vennix, J., den Brok, P., and Taconis, R.: Do outreach activities in secondary STEM education motivate students and improve their attitudes towards STEM?, Int. J. Sci. Educ., 40, 1263–1283, https://doi.org/10.1080/09500693.2018.1473659, 2018.

Villaseñor, T., Celis, S., Queupil, J. P., Pinto, L., and Rojas, M.: The influence of early experiences and university environment for female students choosing geoscience programs: a case study at Universidad de Chile, Adv. Geosci., 53, 227–244, https://doi.org/10.5194/adgeo-53-227-2020, 2020.

Wang, N., Clowdus, Z., Sealander, A., and Stern, R.: Geonews: timely geoscience educational YouTube videos about recent geologic events, Geosci. Commun., 5, 125–142, https://doi.org/10.5194/gc-5-125-2022, 2022.

Welbourne, D. J. and Grant, W. J.: Science communication on YouTube: Factors that affect channel and video popularity, Public Underst. Sci., 25, 706–718, https://doi.org/10.1177/0963662515572068, 2016.

Wyatt, S. and Werner, J.: Using Google Earth to Support Active Learning in an Online Geology Course, Distance Learning, 16, 3–5, 2019.

Wysession, M. E., LaDue, N., Budd, D. A., Campbell, K., Conklin, M., Kappel, E., Lewis, G., Raynolds, R., Ridky, R. W., Ross, R. M., Taber, J., Tewksbury, B., and Tuddenham, P.: Developing and Applying a Set of Earth Science Literacy Principles, Journal of Geoscience Education, 60, 95–99, https://doi.org/10.5408/11-248.1, 2012.