Comparison of in-person and virtual Grand Canyon undergraduate field trip learning outcomes

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Abstract

Field learning is fundamental in geoscience, but cost, accessibility, and other constraints limit equal access to these experiences. As technological advances afford ever more immersive and student-centered virtual field experiences, they are likely to have a growing role across geoscience education. They also serve as an important tool for providing high-quality online instruction, whether to fully online degree students, students in hybrid in-person/remote programs, or students experiencing disruptions to in-person learning, such as during the COVID-19 pandemic. This mixed-methods study compared learning outcomes of an in-person (ipFT) and a virtual (iVFT) geoscience field trip to Grand Canyon National Park, each of which highlighted the Great Unconformity. Participants included introductory and advanced geology students. In the ipFT, students collectively explored the Canyon through the interpretive Trail of Time along the Canyon rim, guided by the course instructor. In the iVFT, students individually explored the Canyon and studied its geology at river level. 360° spherical images anchor the iVFTs and serve as a framework for programmed overlays that enable active learning and allow for adaptive feedback. We assessed cognitive and affective outcomes in both trips using common measures. Regression analysis showed the iVFT to be associated with significantly greater learning gains. The ipFT students had significantly higher positive affect scores pre-trip, reflecting their excitement for the trip. Overall, our results provide clear evidence that high-quality iVFTs can lead to better learning gains than ipFTs. Although field trips are employed for more than just content learning, this finding may encourage greater use of iVFTs in coursework.

1. INTRODUCTION

1.1. On-ground versus virtual field education

Field work is a foundational method of scientific study of Earth systems (Compton, 1962). Its perceived importance among geoscientists and geoscience educators cannot be overstated (e.g., De Paor & Whitmeyer, 2009; Kastens et al., 2009; Petcovic et al., 2014). Moreover, the cognitive, affective, behavioral, and career-related benefits of geoscience learning in the field have been extensively documented (Boyle et al., 2007; Elkins and Elkins, 2007; Fuller, 2006; Gonzales & Semken, 2009; Kern & Carpenter, 1986; Mogk & Goodwin, 2012; O'Connell et al., 2021; Orion, 1993; Pyle, 2009; Riggs et al., 2009; Stokes & Boyle, 2009; Whitmeyer & Mogk, 2009).

Challenges to field geoscience instruction are also numerous and well-documented, including budgetary and liability issues (Baker, 2006; Behrendt & Franklin, 2014); logistical and safety concerns (Baker, 2006; Boyle et al., 2007; Garner & Gallo, 2005; Lei, 2015); and accessibility barriers for students with disabilities (Atchison & Feig, 2011; Atchison & Libarkin, 2013; Carabajal et al., 2017; Cooke et al., 1997; Gilley et al., 2015). Field camps typically require considerable tuition and fees. The need to charge students raises questions of equity and fairness (Boyle et al., 2007; Kent et al., 1997). Similarly, even short field trips place unequal demands on students who work outside of school or those with caregiving responsibilities. Students new to field work may be distracted from learning by concerns over personal safety, comfort, performance, or social interactions with peers and instructors (Elkins & Elkins, 2007; Orion & Hofstein, 1994). Any factors that push students away from geoscience should be particularly concerning for a field that has historically lacked diversity (e.g., Bernard & Cooperdock, 2018; Gillette, 1972). Most recently, although virtual field trips (VFTs) predated the onset of the COVID-19 pandemic, this unprecedented disruption forced educators across disciplines into using VFTs when in-person field trips (ipFT) were not feasible (Kristianova & Joklova, 2020; Rotzien et al., 2021). For all of these reasons, VFTs are likely to see an increase in use, thus making comparative research on their effectiveness even more valuable.

1.2. Virtual field trips and Evidence for Effectiveness

VFTs have long been considered as a possible solution to the challenges summarized above (Stainfield et al., 2000; Steuer, 1992;). Nix (1999) defined a VFT as "an inter-related collection of images, supporting text and/or other media, delivered electronically via the World Wide Web, in a format that can be professionally presented to relate the essence of a visit to a time or place." More recent products have made prominent use of high-resolution graphics, audio, video, 360° images and video, and specialized data such as maps or GIS (Carmichael & Tscholl, 2011; Cassady & Mullen, 2006; Klippel et al., 2020; Mead et al., 2019; 2022). Although most VFTs are not true "virtual reality" (VR), nor do they allow users to walk freely within the virtual space or manipulate objects, they do attempt to provide autonomy and promote learning by allowing interaction with the virtual environment through exploration, analysis, learning, and testing of skills (Stainfield et al., 2000). VFTs allow students to travel the world and beyond without leaving home or campus (Cassady et al., 2008; Lei, 2015). They transport learners to remote, dangerous, and fragile places while avoiding environmental site degradation and reducing carbon footprints (Whitelock & Jelfs, 2005). VFTs can also be used in tandem with traditional field trips, allowing students to maximize their time in the field or mitigating the effects of "novelty space", which recognizes that the novelty of the field may draw attention and focus away from the content of a field learning experience (Arrowsmith et al., 2005; Cliffe, 2017; Orion & Hofstein, 1994; Stainfield et al., 2000). By affording students control and feedback, VFTs enable students to feel as if they are “there,” which in turn impacts understanding and cognitive change (Whitelock & Jelfs, 2005). Nix (1999) states that virtual experiences promote the principles of student-centered inquiry and constructivism. Learners appreciate the interactive nature of multimedia experiences (Pringle, 2013; Robinson, 2009). As delivery and presentation methods continue to improve, VFTs are expected to provide students with greater means of developing their scientific skills such as observation, inference, prediction, understanding, and problem solving (Nix, 1999).

Many existing research studies have shown that VFTs are effective tools for raising interest and engagement (Bursztyn et al., 2017b; Cassady & Mullen, 2006; Klippel et al., 2020; Lei, 2015). A number of studies have directly measured learning gains from VFTs, showing generally positive gains (Bursztyn et al., 2017a; Klippel et al., 2019; Mead et al., 2019; 2022; Stumpf et al., 2008; Whitelock & Jelfs, 2005). There are very few studies that compare learning gains between in-person and virtual field trips and, to our knowledge, no comparative studies of learning gains focused on a browser-based VFT. A study using an augmented reality (AR) Grand Canyon VFT showed that completion of the AR modules was associated with greater conceptual learning gains than a non-AR control group for two of three topic areas (Bursztyn et al., 2017a). In a study using a VR headset-based VFT, Klippel et al. (2019) observed higher lab grades in the VFT group than the ipFT group. Finally, Zhao et al. (2020) conducted a study directly comparing browser-based virtual to in-person field trips and found that students’ self-reported learning experience (a composite measure defined by the authors) was greater in the virtual field trip condition, but learning was not directly measured in this study.

The research to date cautiously suggests the VFTs, whether browser-, VR, or AR-based, are likely to be no less effective than ipFTs at helping students to achieve the many of the learning objectives of such trips. Limitations and uncertainties remain, however, about the range of ways that VFTs might contribute to geoscience education. Most of the VFTs discussed in the literature are completed individually and therefore lack the beneficial social interactions and the ability to bond together a student cohort (Fuller, 2006). If students work from home or in unsupervised computer labs on campus, then the instructor has less control over the learning environment (Lei, 2015; Tuthill & Klemm, 2002). By not emulating sensorimotor, tactile, and olfactory phenomena (Stumpf et al., 2008), VFTs do not yet provide the same complete sensory stimulation as do ipFTs (Nix, 1999; Stainfield et al., 2000) and are inherently an experience once-removed (Robinson, 2009). Virtual experiences also may not allow students to interact in a flexible manner or promote the same level of problem-solving skills that can occur in the actual field environment (Qui & Hubble, 2002). Beyond these specific concerns, there remain deeply-held beliefs among geoscientists that education in the subject is incomplete without in-person field experiences (e.g., Baker, 2006). There is significant support for the idea that VFTs should not replace real-world experiences (Arrowsmith et al., 2005; Cassady & Mullen, 2006; Lei, 2015; Stainfield et al., 2000; Tuthill & Klemm, 2002), but should instead be used as a mechanism to provide prior knowledge that makes the in-person experience more effective (Cliffe, 2017).

Morever, the level of interactivity, immersivity, and pedagogical approach of VFTs vary, all of which play a role in determining the effectiveness of a given VFT. Klippel et al. (2019) defined a typology of VFTs comprising “basic”, “plus”, and “advanced”. These categories distinguish the types of visual perspectives and interactivity provided by the VFT. Mead et al. (2019) defined “iVFT” in contrast to ordinary VFTs in partial agreement with Klippel et al.’s (2019) typology. While iVFTs (as used by Mead et al., 2019) are defined as employing substantial interactivity, they must also provide adaptive feedback (Kulik & Fletcher, 2016; Shute & Towle, 2003; VanLehn, 2011). Such automatic and targeted feedback has been shown to be very effective in other applications of digital learning (Kulik & Fletcher, 2016; VanLehn, 2011). For the present question of the relative effectiveness of virtual or in-person field learning, it is important to acknowledge that in-person field learners will most often be able to ask questions of an instructor at the field site, something that is analogous to personalized computer feedback. Both of these definitions can also be connected to active learning. While a large-scale meta-analysis (Freeman et al., 2014) showed active learning (defined there as any classroom teaching practice that was not lecture) to be more effective than traditional teacher-centered lecture, more mechanistically focused research has highlighted the instructional practices and resultant student behaviors that lead to these benefits (e.g., Chi & Wylie, 2014; Chi et al., 2018; Lombardi et al., 2021). With this in mind, the effectiveness of iVFTs—or, indeed ipFTs—will substantially derive from the degree to which their technological and pedagogical designs promote active learning (Jones & Washko, 2021).

While VFTs are more accessible than ipFT, some barriers remain, and some new ones are introduced. For VFTs, the most difficult of these to overcome is providing an equivalent educational experience for visually impaired students. Screen readers are often used to make digital content accessible, but although thoughtful captioning in the form of “alt text” can help convey the educational content of static images and simple animations (Crow, 2008), the amount of imagery and image-driven interactivity in a typical VFT makes this approach very difficult (e.g., Kim et al., 2021; Lazar et al., 2007; Morris et al., 2018). Other challenges related to the use of digital technology, itself. Despite the widespread myth of the “digital natives”—people assumed to have innate fluency with digital technology simply because they grew up in an age when such technology is ubiquitous—evidence shows this to be untrue (Kirschner & De Bruyckere, 2017; Selwyn, 2009). Thus, educators should ensure that any digital learning resources that they assign are as easy to use as possible and that training is available for students who need it. Lastly, it should not be assumed that all students have equal access to an up-to-date desktop or laptop computer or to high-speed internet. The “Digital Divide” is a term coined in the 1990s, but despite many changes in the technological landscape, gaps in access have persisted (e.g., Van Dijk, 2020). This is a very large-scale issue, but with regard to the use of VFTs in education, designers should take steps to keep bandwidth and hardware requirements to the minimum necessary to achieve their educational goals and educators and institutions should not assume that all students have sufficient hardware and/or bandwidth resources.

Considering the prior research and community preference for ipFTs, there is a need for stronger evidence of comparative learning outcomes of virtual and ipFTs. The present study includes two features that work towards this goal. First, the learning outcome measure is a concept sketch (Johnson & Reynolds, 2005), an assessment that tests higher order thinking and can be scored with partial credit, thus providing fine-grained information about student knowledge. Second, the virtual field trip used in this study, being an iVFT as defined by Mead et al. (2019), includes a structured lesson, interactive elements, and adaptive feedback to facilitate asynchronous learning. Thus, the iVFT studied here provides a pedagogically strong comparison to the typical in-person field learning experience. However, it is also important to clearly state that the iVFT studied does not directly replicate all of the elements of the ipFT. Rather, we suggest that this study should be seen as a comparison between an ipFT and an iVFT that were both designed with the affordances and restrictions of their respective media in mind. We will return to this point in the Discussion.

1.3. The Great Unconformity within Grand Canyon

The specific learning objectives of both the ipFT and iVFT center on interpretations of what is generally known as the Great Unconformity in Grand Canyon. This feature is actually a set of superposed diachronous nonconformities and angular unconformities among Paleoproterozoic metamorphic and granitic basement rocks, Meso- to Neoproterozoic rift-basin sedimentary strata and igneous rocks, and flat-lying Paleozoic sedimentary strata (Karlstrom & Timmons, 2012; Peak et al., 2021). These contacts represent intervals of geologic time long enough to construct and then to fully erode away great mountain ranges. The Great Unconformity extends regionally across western North America (Ricketts et al., 2021) and is notably well-exposed in Grand Canyon National Park (Figure 1).

The Great Unconformity is visible from many points along the Trail of Time (Karlstrom et al., 2008), an interpretive timeline trail along the South Rim of Grand Canyon. It is also fully exposed at river level in many tributary canyons, including Blacktail Canyon—where the multimedia exercise used in the iVFT was filmed. In the portion of the Great Unconformity observed by students on the ipFT to the Trail of Time, 508-million-year old Tapeats Sandstone overlies 1.75- to 1.70 billion-year-old metamorphic and granitic basement rocks of the Granite Gorge Metamorphic Suite and Zoroaster Plutonic Complex (Karlstrom et al., 2012). In the portion of the Great Unconformity featured in the Blacktail Canyon virtual field exercise, the basement rocks that underly the Tapeats Sandstone are 1.84-billion-year-old Elves Chasm Gneiss, but this distinction is not noted in the iVFT. At both localities the “missing time” represents 1.24 to 1.33 billion years, more than one-quarter of the entire history of the Earth.

1.4. Research Questions

This mixed-methods research study was designed to measure and compare learning outcomes of geoscience ipFTs and iVFTs conducted at Grand Canyon National Park. Key instructional resources used in this project were the Trail of Time, used in the ipFT, and a Grand Canyon iVFT developed by the Center for Education Through Exploration at Arizona State University (https://vft.asu.edu). The common learning objective for these experiences was for students to be able to make a geologically accurate drawing of the Great Unconformity and to provide an interpretation describing its major features, origin, and geological significance.

To better understand the specific and comparative advantages of VFTs and ipFTs, we posed the following questions:

Research Question 1: How does achievement of common learning outcomes differ between participants in the ipFT and iVFT?

Research Question 2: What attitudinal differences exist between participants in the ipFT and iVFT?

2. METHODS

2.1 Participants and Procedures

2.1.1 Overview

We conducted the study in two geology courses at a large public research university in a major Southwestern US city. Course 1 was an introductory undergraduate historical-geology course (n = 118) populated mostly by non-geology-majors seeking science credit for general-education requirements. Course 2 was an upper-division undergraduate regional-geology course (n = 62) that served mostly geoscience majors. The enrollments in Course 1 typically represent the demographic diversity of the university as a whole, while enrollments in Course 2 more closely match the demographics of the cohort of geoscience majors (a breakdown of undergraduate student gender and race/ethnicity for the university as a whole, the college, and the home department of the geology program may be found in Table S1). An ipFT to the Trail of Time at Grand Canyon National Park was part of the syllabus in both courses. However, as some students are unable to participate in the ipFT for various reasons (e.g., work or other obligations on the weekend date), all students were given the option to choose either the ipFT (the comparison group) or the iVFT (experimental group), to be done in the same time interval, for equivalent course credit. Both experiences were designed to enable students to explore and learn the geology of the Grand Canyon, including the Great Unconformity (the component of each trip on which this study focuses). We collected quantitative and qualitative data from both groups before, during, and after both learning experiences.

The study was conducted during the Spring (introductory Course 1) and Fall (advanced Course 2) of 2016. The data collection procedures were identical for both courses. The ipFT and iVFT procedures and schedules were also identical, with the exception that the introductory students shared a bus to and from the field site whereas the advanced students arranged their own transportation. This is a minor difference, but relevant because the introductory students were encouraged to complete the post-trip activities on the return trip. With regard to prior instruction on Grand Canyon geology or the Great Unconformity, all of the basic geological concepts related to the formation of Grand Canyon (including principles of unconformities) had been presented in Course 1 prior to the trips, and students in the more advanced Course 2 were expected to have prior knowledge of these concepts. The Great Unconformity, in particular, was covered in Course 1 as an example of a nonconformity when that term was introduced and was discussed in Course 2 in the context of Proterozoic and early Paleozoic geologic history of Arizona.

Students in both courses were given the opportunity to consent to research participation at the beginning of the semester, and those who agreed signed an informed-consent form authorizing the use of their data subject to normal human-subjects protections. The study protocol was approved by our university's institutional review board and designated as exempt research (Study #10515). The number of students consenting to research participation (by course and field trip type) were as follows: Course 1 (ipFT): 38; Course 1 (iVFT): 68; Course 2 (ipFT): 25; Course 2 (iVFT): 25. However, we did have substantially lower completion rates of the assigned tasks among the iVFT groups, with 46 of 68 students in Course 1 completing all tasks and 17 of 25 students in Course 2 completing all tasks. This is compared to 38 of 38 Course 1 ipFT students and 22 of 25 Course 2 ipFT students completing all tasks.

2.1.2. In-Person Field Trip

Student participants in the two ipFTs visited and studied the Grand Canyon as whole-class groups. They took a two-hour guided inquiry hike led by the instructor along the Trail of Time (Figure 2). The instructor on both ipFTs (coauthor SS), was one of the collaborators in designing and constructing the Trail of Time exhibition (Karlstrom & Crossey, 2019; Karlstrom et al., 2008; Semken et al., 2009).

The Trail of Time is laid out as a walkable and wheelchair-accessible timeline scaled and labeled with inset bronze markers so that every meter along the main segment of the trail represents one million years of Earth history. Therefore the entire main Trail is 4.56 kilometers long, although only the easternmost 2 km fully encompasses the history of all rock units that occur at Grand Canyon and the geologically recent incision of the Canyon itself. The two ipFTs took place on this 2-km segment, but students had about two hours of free time after the hike and some opted to walk the additional segment representing the history of the early Earth. Specific times and time intervals corresponding to major geologic episodes in the evolution of Grand Canyon, ages of all Grand Canyon rock units, and (closer to the end of the Trail signifying the present) cultural histories of Indigenous dwellers and later explorers, are variously indicated on the timeline trail with interpretive resources that include wayside interpretive panels, large permanently mounted rock specimens, and viewing tubes that direct the eye to specific features in the landscape (Karlstrom & Crossey, 2019; Karlstrom et al., 2008).

Before beginning the hike, students spent about 30 minutes in a geological museum near the portal to the Trail of Time. This museum is independent of the Trail but presents the same subject matter in a different format. While in the museum and then en route on the hike, ipFT students were tasked with completing a guided-inquiry worksheet. The worksheet was intended to keep students engaged and to direct their attention to the interpretive resources along the trail. The instructor provided additional context during the hike (including anecdotes relating to the design and construction of the Trail of Time), some of which helped students answer worksheet questions. The items on the worksheet consisted of challenge questions the students could answer with simple observations and by means of brief phrases. The worksheet for both the ipFT and iVFT can be found in the Supplemental File S2.

The Great Unconformity was highlighted on the hike. The ipFT students studied it from above, at rim level, using viewing tubes and two wayside panels that were placed to explain its structure, origin, and geologic significance. As at the other interpretive points, the instructor led a brief class discussion of the Great Unconformity, in order to ensure that students could recognize it and write about it on their worksheets. All together, these activities lasted about 20 minutes.

The 2-km segment of the Trail used in both ipFTs ends at Grand Canyon Village, a tourist hub that features cultural museums, gift shops, and three hotels with restaurants. As noted above, when the ipFT groups reached this place they were dismissed for about two hours to enjoy the Village or hike farther along the South Rim as they chose. Their completed worksheets were collected by the instructor on the bus ride back to the university.

2.1.3. Virtual Field Trip

By design, iVFT students viewed the same Grand Canyon stratigraphy that the ipFT students did, although from considerably different vantage points. Learning outcomes related to the Great Unconformity were the same for both trips.

The iVFT used in this study was designed to provide an active, student-centered learning experience bringing students to visually interesting and scientifically significant locations within Grand Canyon. Students were assigned two separate Grand Canyon iVFTs: one following a Colorado River rafting itinerary, stopping at several sites along the main Canyon; the second centered on Blacktail Canyon, placing students within a virtual arm's reach of an exposure of the Great Unconformity. These iVFTs can be found here: https://vft.asu.edu/grandcanyondirect/. In both iVFTs, students move at their own pace within a structure provided the assigned worksheet or the built-in iVFT lesson. Observing rock outcrops is central to field learning. In the iVFTs students make observations from a distance or up close, using the built-in magnification feature. This is further enabled using Gigapans, which allow seamless zooming from panoramic views of rock exposures to views of a few square centimeters in area, all at similarly high resolution. Much like an ipFT, the iVFT interleaves such free exploration with structured activities and short lectures from the expert geologists. As mentioned previously, the student is supported throughout these activities with questions and automatic feedback to ensure that they have understood the key concepts of the lesson.

2.2. Measurement

We designed our data collection to allow us to understand both the cognitive and affective factors associated with in-person and virtual field trips. Cognitive activities, directly linked to learning, involve information processing and meaning construction; while affective processes, such as attitudes, values, beliefs, opinions, interests, and motivation, determine a student's approach to learning and contribute positively or negatively to learning outcomes (Boyle et al., 2007). Learning in the field has been shown to lead to affective responses of students toward the learning situation that improve student outcomes (Kern & Carpenter, 1986; McConnell & van der Hoeven Kraft, 2011; Mogk & Goodwin, 2012). The relationship between cognition and affect is further realized in novelty space (Orion & Hofstein, 1994). Data speaking to cognitive factors included concept sketches, guided inquiry worksheets, and questions about prior knowledge and knowledge gained. Data speaking to affective factors included a modified version of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) and open-ended survey questions about comfort on the trip. A side-by-side description of both field trips and the timing of data collection is provided in Table 1.

2.2.1. Concept Sketches

The structure and origin of the Great Unconformity in Grand Canyon are content elements common to both modalities. All students (ipFT or iVFT) were instructed to create concept sketches of the Great Unconformity from memory, before and after each trip. A concept sketch illustrates the main aspects of a concept or system annotated with concise labels that (1) identify the features, (2) depict the processes that are occurring, and (3) characterize the relationships between features and processes (Anastacio et al., 2006; Johnson et al., 2009; Tewksbury et al., 2004). Student-generated concept sketches require active engagement and a deep level of mental processing (Lawson, 1995; 2003) that leads to the understanding and processing of scientific concepts (Ainsworth & Loizou, 2003) by increasing student involvement in their own knowledge construction (Johnson & Reynolds, 2005). Concept sketching was used regularly in both courses; thus, students were familiar with this activity prior to the start of the study. Students each made and submitted a pre-trip concept sketch during the last class before the field trip. The post-trip concept sketch was submitted by the students in both the experimental and comparison groups during the first class after the trip. The concept sketch prompt and scoring rubric (discussed below) can be found in the Supplemental File S3.

All sketches were scanned and graded using a 17-point rubric designed to assess accuracy and completeness of geologic visualization (8 points) and interpretation (9 points) of the Great Unconformity. Examples of scored sketches are shown in Figure 4. Researchers SS and TJR developed the rubric. A random sampling of eight concept sketches were graded by the authors and one external geoscience expert. Grading discrepancies were noted resulting in rubric modifications. This iterative process was repeated a total of four times. The final version of the rubric was used to grade another set of randomly selected concept sketches by two subject matter experts, achieving a high interrater reliability of 99%. The remaining concept sketches were graded by a single researcher (TJR) using the final rubric. Pre- and post-trip concept sketches of the Great Unconformity were scored with no knowledge of chosen field-trip modality.

2.2.2. Affect survey

Pre- and post-trip surveys were administered to investigate cognitive and affective factors. Given the known relationship between cognition and affect in field-based instruction, we administered a modified PANAS instrument (see Supplemental File S4) to students in both the comparison and experimental groups before and after the field experience to assess attitudes and cognitive-load factors for each group. The comparison-group pre-trip survey was administered prior to the start of the Trail of Time walk, and the post-trip survey was administered immediately following the end of the walk. The virtual pre-trip survey was administered immediately before starting the digital experience and the post-trip survey was administered immediately after completion of the iVFT.

The original PANAS instrument of Watson et al. (1988) contains ten positive affect (PA) and ten negative affect (NA) categories. The modified survey administered to students eliminated three choices from each category that did not pertain to the educational environment. The modified instrument contains the positive categories *interested*, *excited*, *enthusiastic*, *inspired*, *attentive*, *active*, and *curious*; and the negative categories *distracted*, *bored*, *confused*, *passive*, *overwhelmed*, *unfocused*, and *uncomfortable*. Students are asked to rate the degree to which each word describes their feelings and emotions on a Likert scale from 1 to 5. Positive and negative categories are summed separately to determine a PA and NA score. These modified scales each had reasonably high reliability as measured by Cronbach's α (α_{pa} = .89, α_{na} = .76). We calculated mean scores for each field trip modality and course. To examine the possible impact of field-trip modality on student affect, we performed a two-sample t-test comparing ipFT and iVFT students within each course and at each time point.

2.2.3. Guided Inquiry Exercises

The ipFT (comparison group) and iVFT (experimental group) participants each completed a guided-inquiry exercise drawn from elements of the Trail of Time at Grand Canyon at the start of the experience (Supplemental File S1). Both groups completed their exercises on paper. The comparison group completed their exercise during the two hours spent walking the Trail of Time and submitted the completed exercise either at the end of the walk (advanced course) or on the bus ride back to campus (introductory course). The experimental group was directed to print out a worksheet and to complete the exercise while carrying out the first half of the iVFT: a virtual geological exploration of Grand Canyon intended to provide a synthesis of Canyon geology similar to what the comparison-group students experienced during their walk on the Trail of Time. This group submitted their worksheets in the first class after the iVFT. All worksheets for both modalities were graded by the course instructor.

2.2.4. Open-Ended Questions

We administered a number of short, open-ended questions to students in both the comparison and experimental groups to characterize their responses to the field experience and to contextualize the quantitative PANAS data. Because the questions related closely to each experience, the questions differed slightly for the comparison and experimental groups. The full list of questions may be found in Supplemental File S3.

Student responses to the open-ended questions were reviewed using inductive coding (Creswell, 1994). In order to be sensitive to emergent themes, no specific hypothesis was formulated. Individual student responses were analyzed using constant comparison methods (Glesne & Peshkin, 1992). Quotes were assigned to the themes that emerged from the data, and student responses often contained multiple quotes assignable to more than one theme.

3. RESULTS

3.1. Concept Sketches

We use the pre-/post-trip concept sketch scores to address research question 1 (How does achievement of common learning outcomes differ between participants in the ipFT and iVFT?).

The same concept sketch exercise was completed by participants in both courses and in both modalities before and after the field trip. The concept sketches had a maximum score of 17 (see Methods for scoring details). Average pre- and post-trip scores for both courses and modalities are shown in Table 2. To determine whether there was a significant overall difference in performance associated with field trip modality, we performed a linear regression. Our initial regression model predicted post-trip score as a combination of modality (ipFT or iVFT), course (introductory or advanced), and pre-trip score. Results showed the course level to be a non-significant predictor (either on its own or through an interaction effect with modality), so the final model was simplified to include only modality and pre-trip score.

Our regression results show that the iVFT was associated with significantly higher post-trip concept test scores than the ipFT. The non-significant contribution of course suggests that this improvement was found at both the introductory and advanced levels. The regression model results are shown in Figure 5 and Table 3. In addition to the overall concept test scores, Table 2 presents the interpretation and visualization subscore means. These data show that the modality effect was somewhat stronger with respect to improvement in interpretation, although the iVFT students showed larger gains on both subscores.

3.2. PANAS Results

We calculated mean PA (positive affect) and NA (negative affect) scores pre- and post-trip for each course and field trip modality (Figure 6). The ipFT students reported significantly higher PA scores pre-trip in both courses; this difference persisted post-trip in the advanced course, but not the introductory course. The ipFT students reported lower NA scores in both courses and at both time points, although this difference was significant only pre-trip in the introductory course. We also examined pre- to post-trip changes in affect scores within course/modality subgroups. Of these, only the introductory iVFT students' NA score exhibited a statistically significant change (in this case, a decrease in NA post-trip).

3.3. Guided-Inquiry Exercises

Each field-trip modality incorporated a guided-inquiry exercise. Because the answers to these questions were contained within the content of each field trip (ipFT or iVFT) and because the exercises could be completed collaboratively during the field trip, the scores on these exercises should primarily be interpreted as reflecting student engagement and participation. The Course 1 ipFT group averaged a score of 98% and the Course 1 iVFT group averaged a score of 92%. The Course 2 ipFT group averaged a score of 94% and the Course 2 iVFT group averaged a score of 96%. The high scores suggest that students were actively engaged with the instruction irrespective of level or modality.

3.4. Open-Ended Questions

Upon completion of the Blacktail Canyon Virtual Field Trip, iVFT students were asked the following: "Having completed this immersive Virtual Field Trip, are you more or less interested in visiting Grand Canyon in person? Please briefly explain your answer."

There were 49 respondents from the Course 1 iVFT (experimental) group and 11 respondents from the Course 2 iVFT (experimental) group. 88% (43/49) of the Course 1 iVFT students and 91% (10/11) of the Course 2 iVFT students responded that they were more interested in an in-person visit to the Grand Canyon after finishing the virtual experience (Fig. 7). Emergent themes from this question included: Experience in Person (passive), Interact with Geology (active), and Inspired by iVFT. Considering the emergent themes, Course 1 students commonly expressed ideas of experiencing the Canyon or being inspired by the iVFT. The more advanced Course 2 students were more likely to additionally indicate an interest in more actively interacting with the geology of the Canyon (Fig. 8). The coding rubric for these and all other emergent themes can be found in Supplemental File S5.

After completing the field trip, ipFT and iVFT participants were asked the following question: “Please list and describe any factors that made it difficult for you to learn Grand Canyon Geology today.”

For this question, there were 38 respondents from the Course 1 ipFT (comparison) group, 22 respondents from the Course 2 ipFT (comparison) group, 44 respondents from the Course 1 iVFT (experimental) group, and 11 respondents from the Course 2 iVFT (experimental) group. Emergent themes from this question for the ipFT participants included: Trail Conditions, Student Experience (e.g., difficulty hearing the professor or difficulty seeing the rock features), Field Trip Content, Personal Challenges, and No Difficulties. Emergent themes from this question were different for the iVFT participants and included: Technical Difficulties, User Experience / Interface, iVFT Content, Personal Challenges, and No Difficulties. The percentage of each group selecting a particular theme can be found in Figs. 8–10.

4. DISCUSSION

4.1. Research Question 1: How does achievement of specified learning outcomes differ between virtual and in-person field trip participants?

Our analysis of pre- and post-trip concept sketch scores reveals that, in both courses studied, the iVFT was associated with greater improvements on the concept sketch activity than the ipFT. On its face, this is a surprising result, particularly given the strong support that field education has in the geoscience community; it is, however, consistent with Zhao et al.’s (2020) results measuring *perceived* learning. Thus, it is important to examine the factors that could explain the superior learning outcomes of the iVFT in our study. We will consider (1) the validity and relevance of the assessment; (2) differences in the amount of instruction between conditions; (3) differences in the content of instruction between conditions; and (4) differences in the manner of instruction between conditions.

First, there is the question of our assessment and its alignment to the instructional material in both field trips. The two trips did not have a one-to-one correspondence in structure, but a description and explanation of Great Unconformity geology as exposed at Grand Canyon was a key element of both field trips and in both cases was intended to be a specific learning outcome. The concept sketch exercise was designed by a subject expert; it was directly relevant to the task; students had previous experience with the concept sketch technique; and the scoring rubric had high reliability, all of which support the validity of the assessment. Concept sketches are also an ideal technique for capturing student understanding of geology, being designed to assess both the visual and descriptive elements of the geology content (Johnson & Reynolds, 2005). Finally, the measurement was sufficiently difficult to avoid a ceiling effect on the post-trip assessment. Thus, it is unlikely that our results were due to a flaw in the outcome measure.

Second, in comparative studies in education, it is important to consider the amount (duration) of instruction across conditions. In both cases, students received instruction on the geology of Grand Canyon, generally, as well as on the Great Unconformity, specifically. In the iVFT, students completed two separate activities: the first was a virtual rafting trip down the Colorado River with instruction about the geology of the Canyon in general; the second took students to Blacktail Canyon and was largely about the Great Unconformity. In the ipFT, students took part in a number of different activities, including visiting the museum and taking both guided and unguided hikes along the rim. Within this, around 20 minutes of focused time was spent on the Great Unconformity (see Figure 2). Overall, the ipFT students had a far longer educational experience (multiple hours in total), but proportionately less of it was spent learning about the Great Unconformity specifically. As for the difference in absolute time spent, the two sets of instruction were similar in length, although the iVFT was probably slightly longer. However, because the iVFT was self-guided, we cannot precisely compare the time spent on the two experiences. In summary, the duration of instruction and/or the focus of instruction could have been a factor in explaining our results.

Third, it is important to consider the visual and geologic content in each condition. The ipFT students experienced the Grand Canyon and the Great Unconformity at rim level via wayside panels and viewing tubes, with the actual feature visible but miles away. The iVFT students experienced the Grand Canyon and Great Unconformity (virtually) at river level via close-up, high resolution photos and a video lecture that placed the professor immediately in front of the feature while pointing and touching the unconformity. Although these perspectives are very different, both field trips provided students with the information necessary to score well on the concept sketch assessment. Therefore, our results do not stem from a failure to include all relevant content in the ipFT condition, but we cannot rule out the possibility that Blacktail Canyon, even studied virtually, is an inherently more effective vantage for teaching about the Great Unconformity than the canyon rim.

Finally, there are two important differences in the manner of instruction that could explain our results. As described in the introduction, a key goal in the design of iVFTs such as Blacktail Canyon is to use interactivity and adaptive learning technology to promote active learning. Thus, it is reasonable to ask whether the iVFT students learned more because that trip made better use of active learning than the ipFT. This possibility is supported by the observation that most student engagement during the ipFT was “passive” or “active” in the sense of the ICAP framework (Chi & Wylie, 2014), in that students listened to the instructor, made observations of natural and interpretive features where prompted, asked clarifying questions, and wrote responses to prompts, but for the most part added no information beyond what they were tasked to document. This also matches the conclusions of Jones & Washko (2021), whose review of field trip pedagogy identified active learning as central to their educational effectiveness.

The second important difference in the manner of instruction between the two trips is that the iVFT students learned in a familiar environment (i.e., their home or a campus location) while the ipFT students learned in a new and potentially distracting environment. Hence novelty space may be a factor, as previous research has shown that it can reduce learning if students are not suitably prepared for learning in this new environment (e.g., Orion & Hofstein, 1994). In fact, Cassady & Mullen (2006) note this as one potential advantage of VFTs. Between the relatively higher use of active learning in the iVFT and the possible influence of novelty space in the ipFT, it is likely that the manner of instruction was an important factor in explaining our findings.

4.2. Research Question 2: What attitudinal differences exist between virtual and in-person field trip participants?

Evidence from the PANAS survey and the post-trip open-ended questions highlight some moderate differences in student affect between the two field trip modalities. The PANAS data revealed significant attitudinal differences, primarily pre-trip, between students in the two field trip modalities. Students in the ipFT groups in both courses reported significantly higher pre-trip positive affect (PA) scores and ipFT students in the introductory course also reported significantly lower pre-trip negative affect (NA) scores. This is somewhat at odds with prior research on VFTs. Notably, Klippel et al. (2019), in a study involving a VR headset-based VFT; and Zhao et al. (2020), in a study involving both VR and desktop-based VFTs, found that the

VFT students reported greater enjoyment than ipFT students. Bursztyn et al. (2017a) also found AR field trips to increase interest in learning geoscience. However, this difference in outcomes may be explained by the fact that the ipFT in this study was a day-long trip to Grand Canyon and not a short visit to a road cut.

So while it may not be surprising that students taking a trip to Grand Canyon would report greater excitement or feel more inspired than students completing an activity on their computer at home, the relevant question is if this enthusiasm gap for the iVFT students was detrimental to learning. It is now accepted that student affect plays an important role in student learning (Kern & Carpenter, 1986; McConnell & van der Hoeven Kraft, 2011; Mogk & Goodwin, 2012; Orion & Hofstein, 1994; Watson et al., 1988). The original PANAS study was validated on a sample of undergraduate students (N = 660) providing a baseline comparison for “typical” PA and NA values (PA = 2.97, NA = 1.48; Watson et al., 1988). Because we altered the instrument, we will use these values only as a general point of reference. With the exception of the pre-trip, introductory Course 1 iVFT students, all groups had average PA scores above the baseline, with the highest scores being the more advanced Course 2 ipFT students. All groups had average NA scores above the reference value (i.e., more strongly negative), with the highest scores being those of the pre-trip iVFT students in both courses. Overall, this suggests that the iVFT students had unremarkable affective states, in contrast to the ipFT students, who had elevated positive affect compared to a typical baseline.

The main takeaway from the open-ended questions was a contrast by field-trip modality in the factors that students reported as hindering learning. Typical ipFT responses included fatigue, trouble hearing the professor outdoors, and distracting crowds at the Canyon rim, whereas the iVFT students were limited by factors like the website user interface or internet connectivity. We also found some differences between courses; most notably, the Course 1 students on the ipFT were far more likely than the Course 2 students to report issues with learning related to hiking. Given that most of the more advanced students had prior experience on geologic field trips, this difference highlights the ways in which students' personal experiences (academic, recreational, etc.) can shape their enjoyment of and comfort with field learning (e.g., Orion & Hofstein, 1994). In the present study, these factors did not lead to a significant difference in the relative effectiveness of the iVFT between the courses. However, it is possible that under different circumstances the iVFT could have been even more valuable for students with less field experience.

4.3. Implications for Practice

Our results add to a growing body of evidence that browser-based iVFTs are an effective approach for geoscience education (Mead et al., 2019; 2022; Zhao et al., 2020). Educators who are not in a position to offer an ipFT can be confident that a well-designed iVFT can achieve conceptual learning gains on par with an ipFT. When generalizing our results, it is essential to recognize the design features of the iVFT. As detailed in Mead et al. (2019), iVFTs are designed to promote active learning by including interactive elements and through adaptive feedback. Because of the well-known value of active learning and because the ipFT in our study was in practice more passive (in the sense of the ICAP framework; Chi & Wylie, 2014) than the iVFT, we believe this to be an important factor in our findings. Thus, we recommend that practitioners pay close attention to the degree of active learning in any iVFT.

Beyond differences in pedagogy, it is also important to recognize that the ipFT and iVFT studied also differed in how and from what distance students were able to view the key rock outcrops. As discussed, this may have contributed to the greater learning for the iVFT students. It also means that we cannot directly argue that iVFTs will be more effective than ipFTs in situations where they are identical (although Zhao et al., 2020 did find that to be true). That being said, it is worth reiterating that the capacity to bring students, virtually, to the clearest example of any given geologic concept is one of the primary advantages of iVFTs.

In the study, we asked students to describe obstacles to learning that they encountered. For the ipFT students, many of these obstacles could be described as issues of novelty space (Elkins & Elkins, 2007; Orion & Hofstein, 1994). This occurred even though the ipFT students received prior preparation to help them anticipate the challenges they would encounter in the field. One natural synergy between iVFTs and ipFTs is to assign an iVFT in advance of the ipFT to increase students' familiarity with the environment and content of the trip (Arrowsmith et al., 2005; Cliffe, 2017; Orion & Hofstein, 1994; Petterson et al., 2021; Stainfield et al., 2000). This prior work suggests that an iVFT carried out before the ipFT can reduce novelty space and positively impact learning.

Our study did find evidence that speaks to the distinctive value of traditional ipFT. In both courses studied, the ipFT students reported significantly stronger positive affect, indicating their excitement and anticipation for the field trip. These emotions connected to field geology are an important pathway into the profession (LaDue & Pacheco, 2013). Importantly, because our assessment focused on content knowledge, the extent to which iVFTs can be effective in teaching specific field skills or help students solve complex, integrative problems in field geology is not addressed here.

Finally, although iVFT students need not set aside an entire day, our results suggest that they may benefit from protecting some time to focus on their virtual experience. On the question of barriers to learning for iVFT students, obstacles included technical matters, such as difficulty with the web-browser interface for the iVFT, internet connectivity, and even the lack of a printer (for the required exercise). They also included environmental issues, such as distractions from people around the student. Our results cannot speak directly to this, but it may be useful to encourage students to treat these iVFTs more like an on-ground field trip in that they should schedule a block of time for it and avoid interruptions more carefully than they might for a normal homework activity.

4.4. Limitations

One significant limitation of this study is that it was not possible to employ random assignment of treatment conditions. Students were allowed to choose either the ipFT or the iVFT experience, which may have introduced self-selection biases. One possibility is that geology majors in the advanced class were drawn to the ipFT because they enjoy working in the field. Another is that students who were familiar with online courses, technology, or video games may have preferred the virtual experience. This issue could explain the unequal pre-test scores on the concept sketch activity in the advanced class, but it does not seriously undermine the study's main findings. This is particularly true considering that the introductory class had no such pre-trip difference. In addition, the Course 1 iVFT students has a much lower completion rate for the concept sketch, the research survey, and open-ended questions, which raises concerns about a biased comparison. Here again, we argue that the similarity of the pre-trip concept sketch scores bolsters our claim that the between group comparison is meaningful, but this does underscore the limitation of employing non-experimental research methods. Relatedly, it is also limiting that this study was conducted at only one southwestern U. S. university and in only two geology courses; a more expansive study is needed for more robust findings.

Another limitation is that the participating students had good access to computer technology and internet connectivity as well as some familiarity with online digital learning environments. As such, our findings may not be applicable to students of different cultures or with different economic or technological resources.

4.5. Future Work

This study assessed learning through a concept sketch activity. Although this is a strong assessment, it captures only one facet of the learning that could have occurred on a geologic field trip. Future work could explore outcomes related to knowledge transfer—understanding new, but related, geologic settings. It could examine procedural knowledge, such as the use of measurement tools. Studies could look into the longitudinal impact if iVFTs are used multiple times across a curriculum. Or work could more directly examine affective outcomes such as motivation or intent to pursue a career in geoscience. With a more mechanistic perspective, we argued that a significant factor in explaining our findings was the use of active learning. The ICAP framework (Chi & Wylie, 2014; Chi et al., 2018) provides a means for operationalizing active learning, which could help to explain the specific effectiveness of and best practices for both in-person and virtual field trips.

We have already noted that the ipFT and iVFT studied here were not directly equivalent and have argued that this follows, in large part, from the particular strengths and limitations of the two modalities. As iVFTs designs grow more ambitious and sophisticated and as research around iVFTs becomes more varied in the types of learning outcomes studied, we, as a community, should work towards creating a complete picture of how the strengths of iVFTs (both pedagogically and practically) can benefit geoscience education across the curriculum and at varying levels of formal or informal education. This will likely include contributions like Zhao et al. (2020), in which equivalent in-person and virtual experiences are compared, and contributions like our own, in which less directly equivalent experiences are compared in recognition of practical considerations common to most instructional settings.

5. CONCLUSION

Field learning is acknowledged to be central to geoscience education and is viewed as an effective way to learn geology. However, not all students have equal access to field-based learning because of time, cost, distance, ability, instructor availability, and safety constraints. At the same time, technological advances afford ever more immersive, rich, and student-centered virtual field experiences. Virtual field trips may be the only practical options for most students to explore pedagogically rich but inaccessible places. We have shown that some learning outcomes from an iVFT can exceed those from an ipFT, even to a location as iconic and pedagogically powerful as Grand Canyon, suggesting that well-designed virtual field trips incorporating active learning are a suitable alternative when in-person field trips are not available and, in some cases, may even serve as an effective replacement for field-based learning.

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The authors report there are no competing interests to declare.

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Table 1. Comparative field trip itineraries and timing of data collection.

<table>
<tr><th>ipFT Itinerary</th><th>iVFT Itinerary</th></tr>
<tr><td colspan="2">- Concept sketches introduced in class at the beginning of the semester
- The Great Unconformity introduced in class approximately two months prior to field trip
- Pre-Trip Concept Sketch assigned and submitted in last class meeting before field trip</td></tr>
<tr><td>- Pre-Trip PANAS Survey and open-ended questions administered on morning of field trip
- Exploration of Grand Canyon & Trail of Time Guided Field Trip with Professor at rim level
- Guided Inquiry Exercise administered during field trip & collected after field trip
- Post-Trip PANAS Survey & open-ended questions administered after field trip</td><td>- Pre-Trip PANAS Survey and open-ended questions administered at start of virtual field trip
- Virtual exploration of Grand Canyon geology from river level and guided inquiry exercise worksheet submitted after completion
- Virtual exploration of Blacktail Canyon and the Great Unconformity at river level
- Post-Trip PANAS Survey & open-ended questions administered immediately after Blacktail Canyon virtual field trip and submitted after field trip</td></tr>
<tr><td colspan="2">Post-Trip Concept Sketch assigned and submitted in first class meeting after field trip</td></tr>
</table>

Table 2. Concept sketch scores.

Course	Modality	Time	N	Overall[1]		Interpretation[2]		Visualization[3]	
				Mean	SD	Mean	SD	Mean	SD
Course 1	ipFT	pre	38	7.03	2.87	1.53	1.70	5.50	1.70
Course 1	ipFT	post	38	7.84	2.92	1.84	1.55	6.00	1.83
Course 1	iVFT	pre	46	7.09	2.36	1.46	1.21	5.63	1.81
Course 1	iVFT	post	46	9.61	2.71	3.02	1.90	6.59	1.71
Course 2	ipFT	pre	22	8.5	3.28	2.18	1.59	6.32	2.01
Course 2	ipFT	post	22	9.23	2.37	2.23	1.45	7.00	1.38
Course 2	iVFT	pre	17	6.71	3.33	1.59	1.28	5.12	2.37
Course 2	iVFT	post	17	9.06	2.9	2.53	2.03	6.53	1.50

[1] Maximum score 17 points; [2] Maximum score 9 points; [3] Maximum score 8 points

Table 3. Regression model summary

Variable	Beta	SE[1]	p-value
(Intercept)	4.8	0.667	<0.001
Experimental Condition			
ipFT	—	—	—
iVFT	1.4	0.443	0.002
Pre-score	0.46	0.078	<0.001

[1]SE = Standard Error

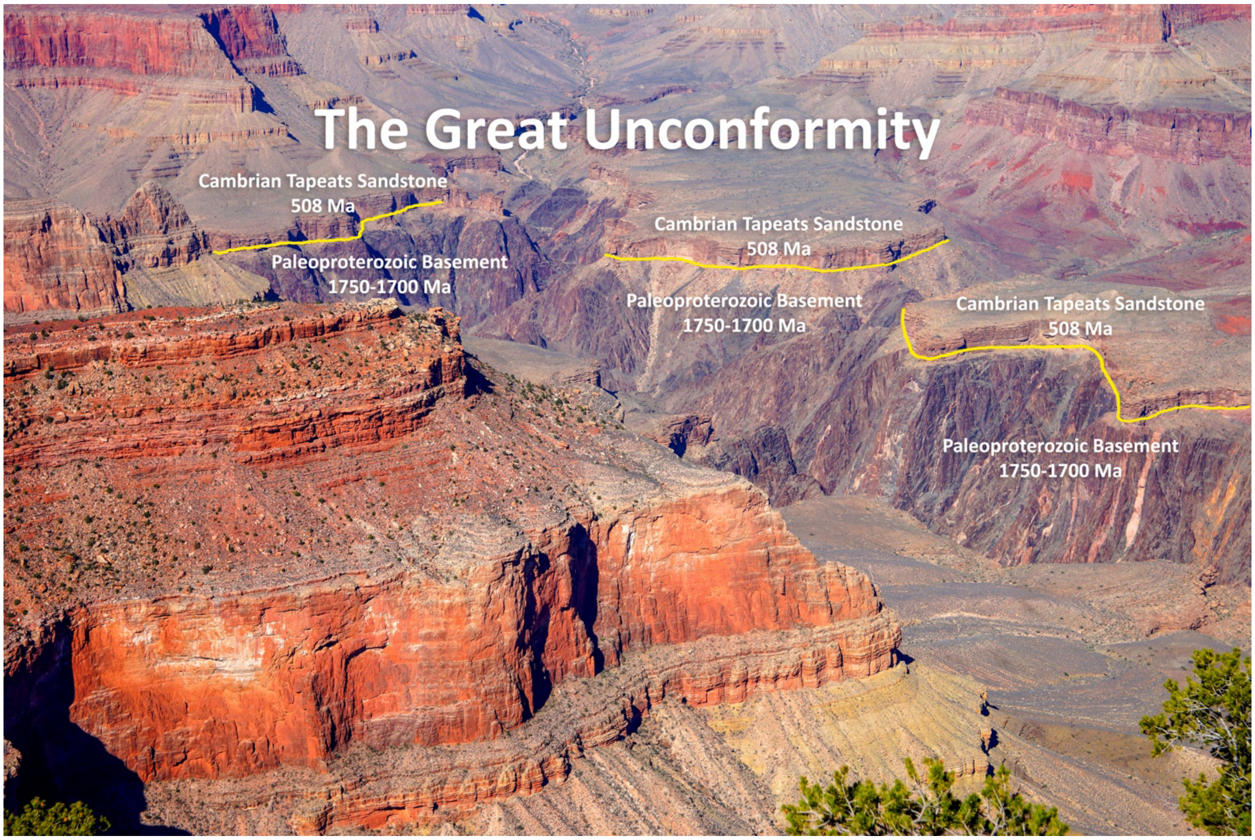


Figure 1. The Great Unconformity. The Great Unconformity as seen from the South Rim of Grand Canyon. The yellow line marks the nonconformity between 1.75-1.70 Ga (Paleoproterozoic) basement rocks and 508 Ma (Cambrian) Tapeats Sandstone. The 1.84 Ga Elves Chasm Gneiss featured in the Blacktail Canyon iVFT is not visible here.

Figure 2. Trail of Time (in-person) field trip. ipFT students prepare to embark on a guided inquiry of the Grand Canyon along the Trail of Time (A) with their professor (F) and later view the Layered Paleozoic, Grand Canyon Supergroup, and Vishnu Basement rocks from a distant, rim level perspective. The Great Unconformity is experienced via two wayside panels (D, E), viewing tubes (C) at rim level perspective, and an on-site lecture (B).

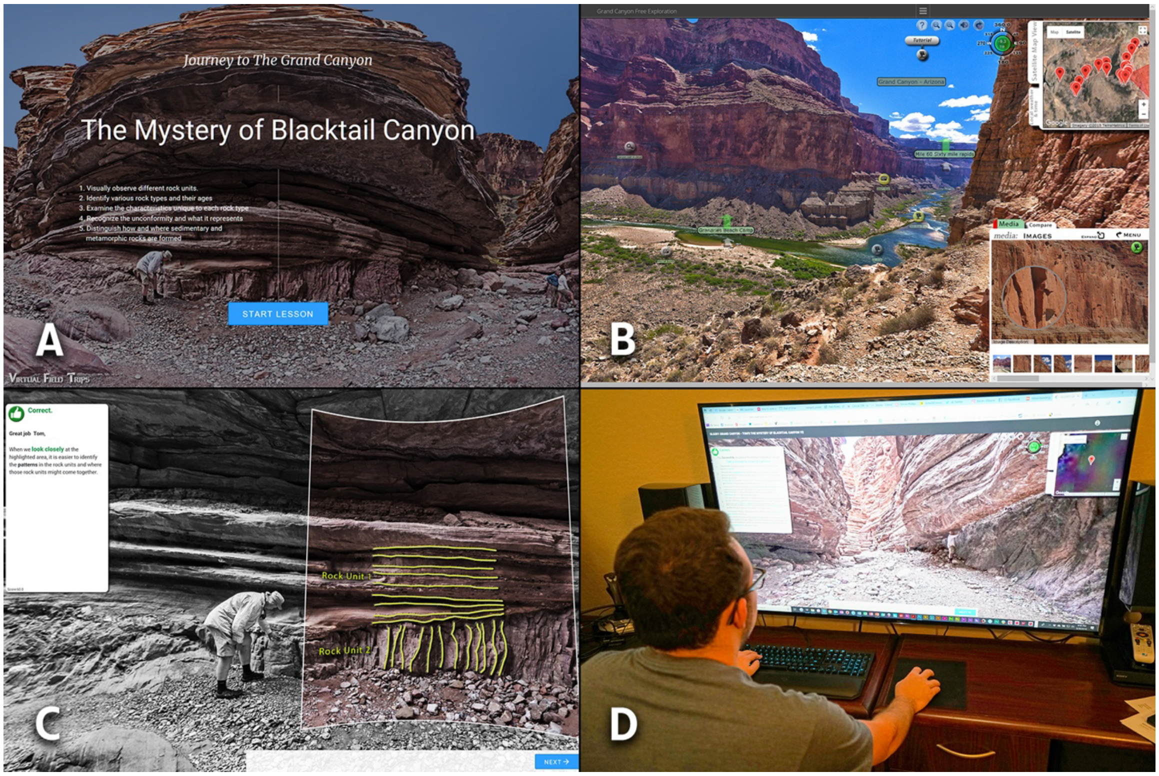


Figure 3. An iVFT student (D) views the Blacktail Canyon virtual field trip (A) through an up close, river level perspective. Hotspots (B) allow iVFT students to interact with the Great Unconformity in Blacktail Canyon using high-resolution photos and videos of rocks and other features at an up close, river level perspective. Interactive features within the Smart Sparrow platform allow for overlays and annotations (C) not possible in the field.

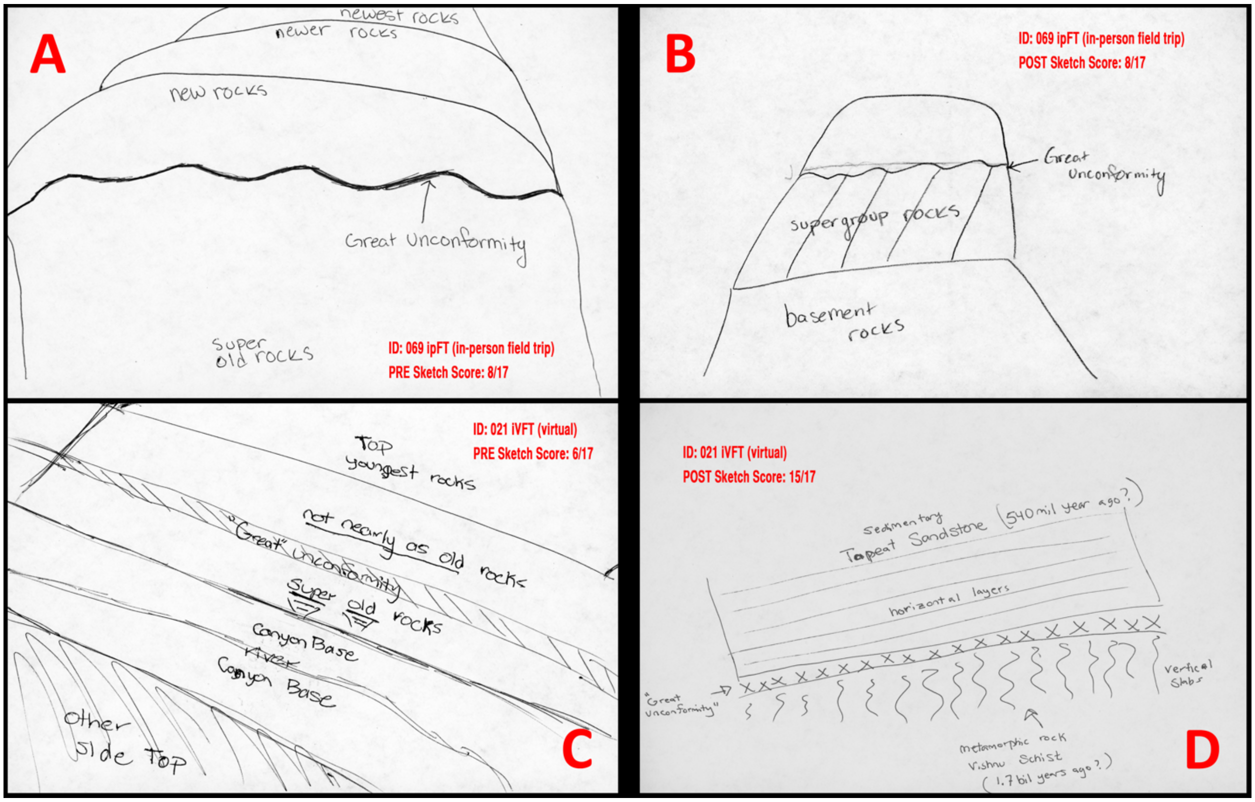


Figure 4. Concept sketches. The top sketch is a pre (A)-to-post (B) comparison for an ipFT student. Although different, both contain the same amount of information. The pre (A) and post (B) scores are the same: 8 out of 17 points. The bottom sketch is an iVFT student pre (C) to post (D) comparison. Although they look similarly complex, the post sketch contains significant amounts of interpreted knowledge. The pre (C) and post (D) scores are very different: 6/17 vs. 15/17.

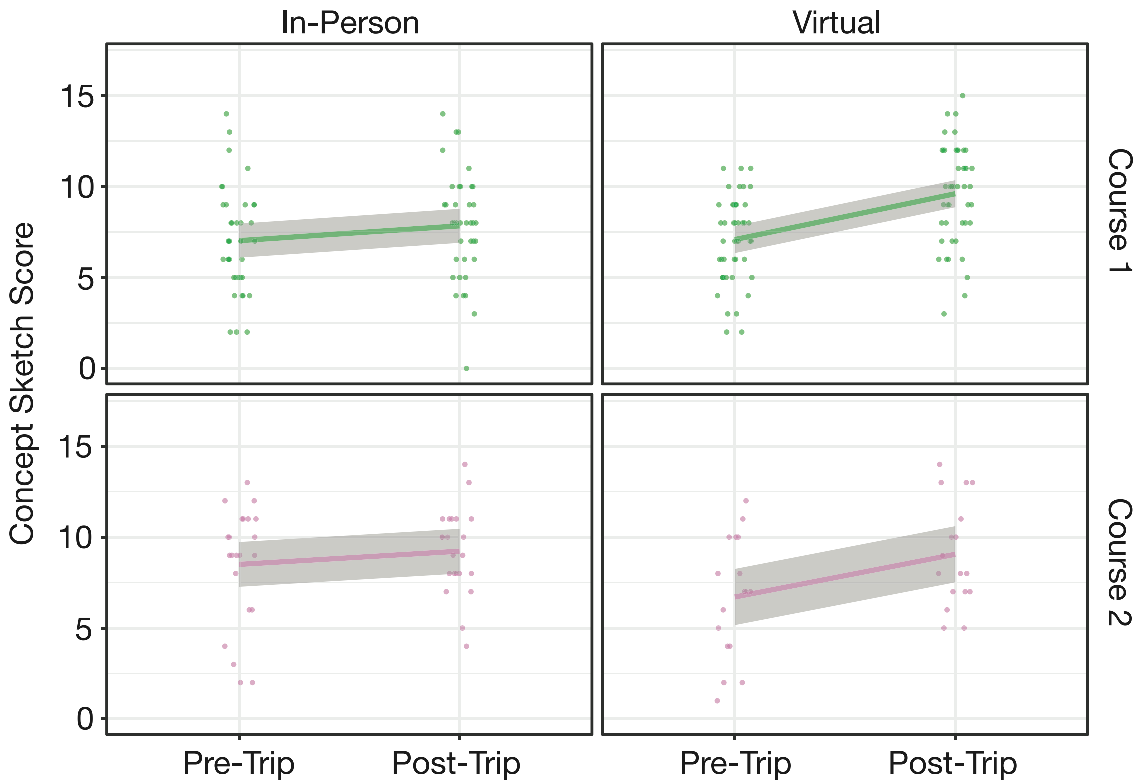


Figure 5. Individual pre- and post-trip concept sketch scores by course and field trip modality.

Plotted slopes are calculated per subgroup. Errors shown represent ±2SE about the mean.

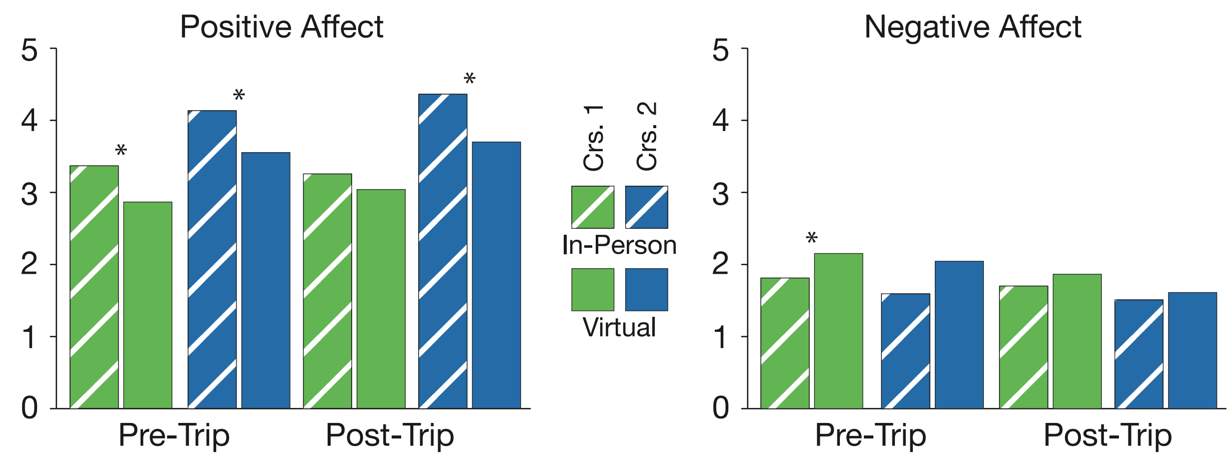


Figure 6. Mean positive affect and negative affect scores by field trip modality, pre-/post-trip for each course. Statistically significant between-modality differences ($p < .05$) are indicated with asterisks.

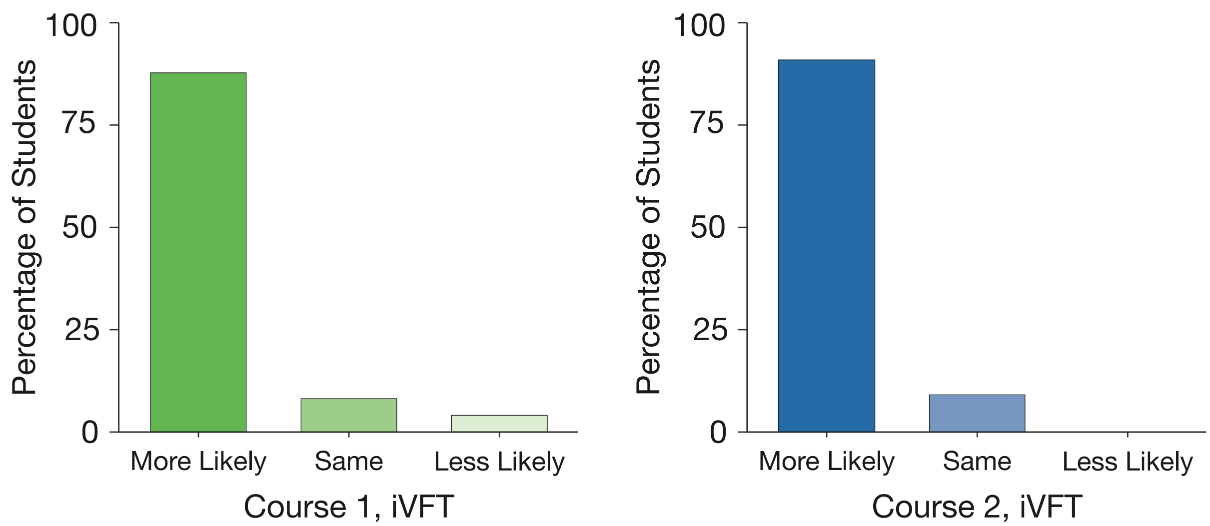


Figure 7. Self-reported interest for iVFT group in a future in-person visit to the Grand Canyon. Response counts: Course 1 = 49; Course 2 = 11.

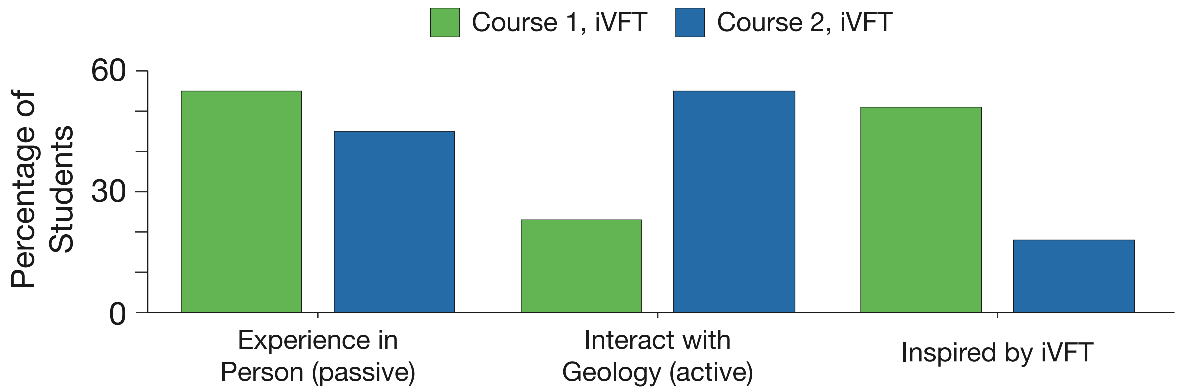


Figure 8. Coded explanations for iVFT students were interested in an in-person Grand Canyon visit. Course 1 students were more likely to give passive or affective explanations while Course 2 students were more likely to talk about interacting with the geology of the Canyon. Response counts: Course 1 = 49; Course 2 = 11.

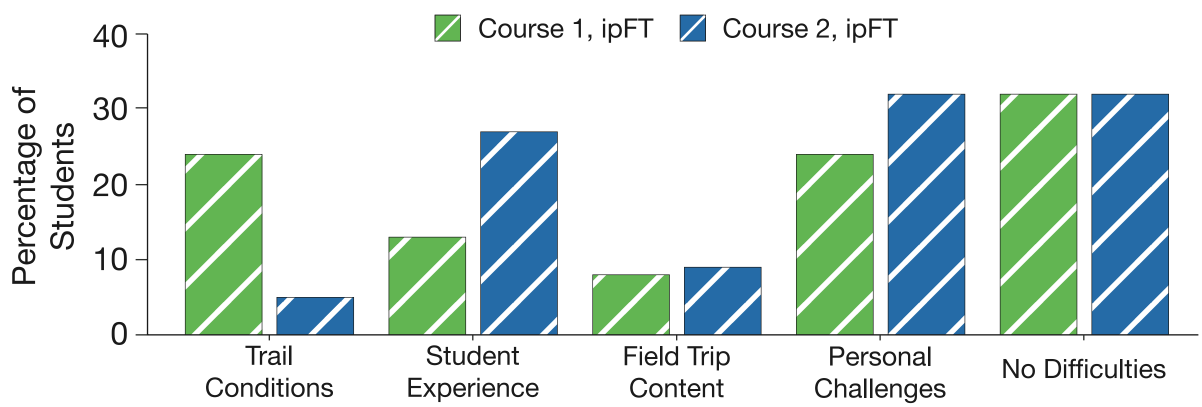


Figure 9. Self-reported factors that made it difficult for ipFT students to learn Grand Canyon geology. Response counts: Course 1 = 38; Course 2 = 22.

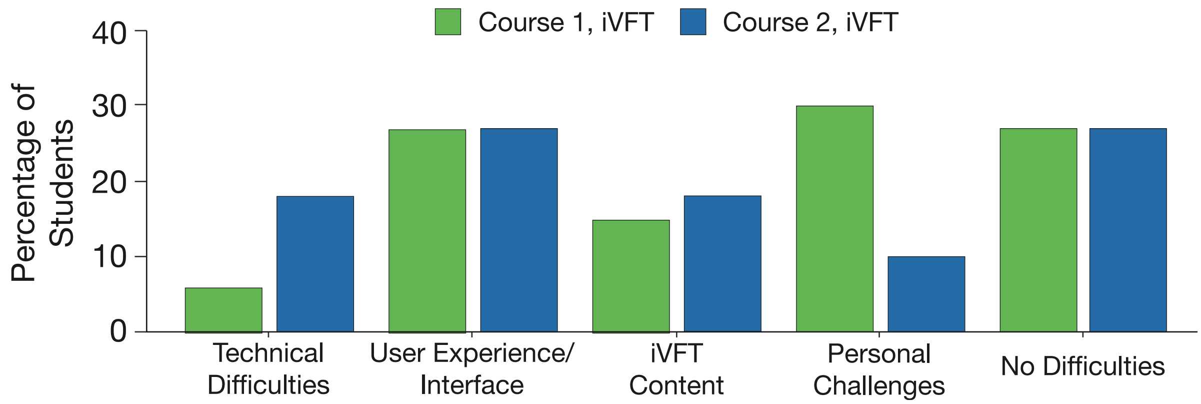


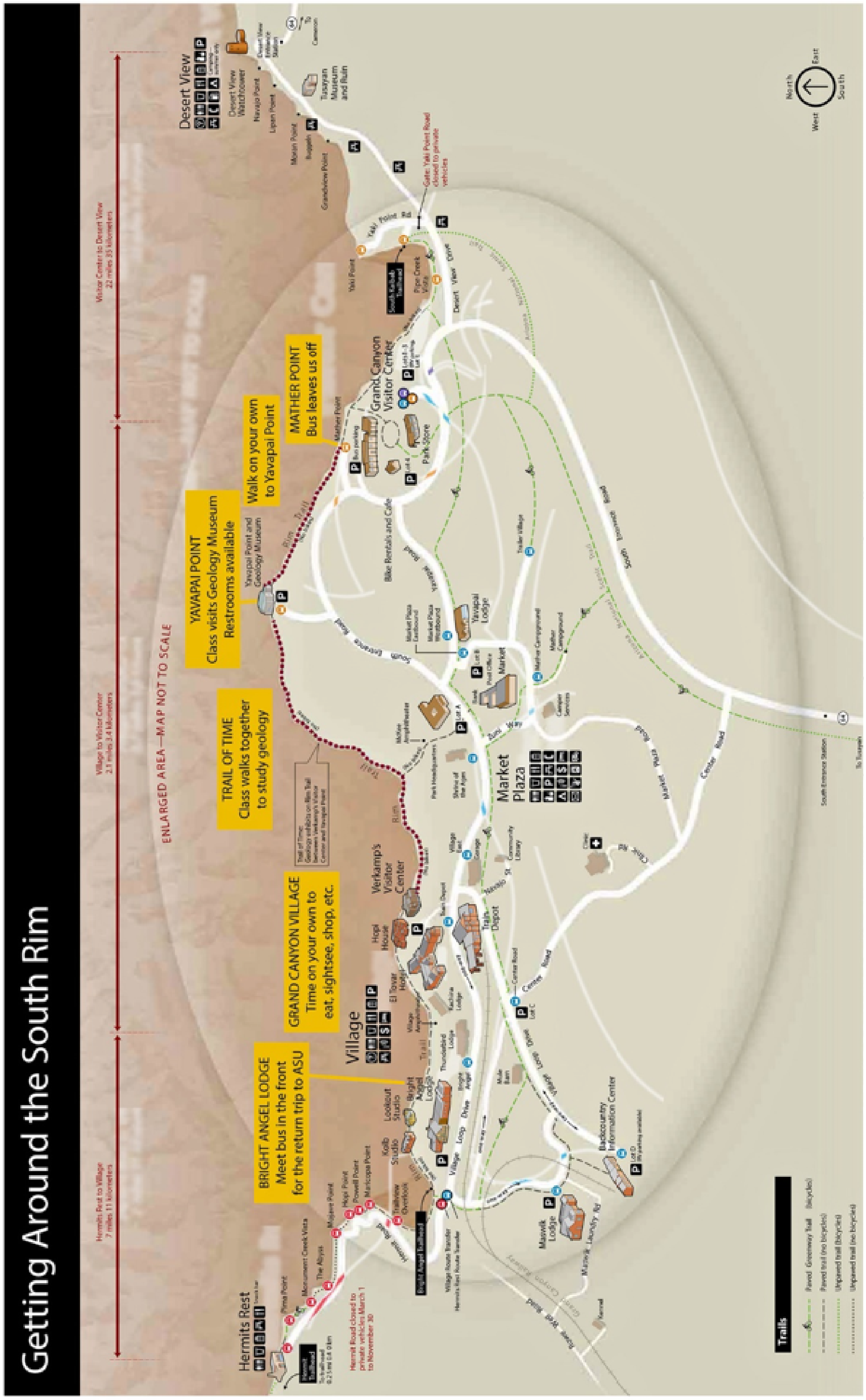
Figure 10. Self-reported factors that made it difficult for iVFT students to learn Grand Canyon geology. Response counts: Course 1 = 44; Course 2 = 11.

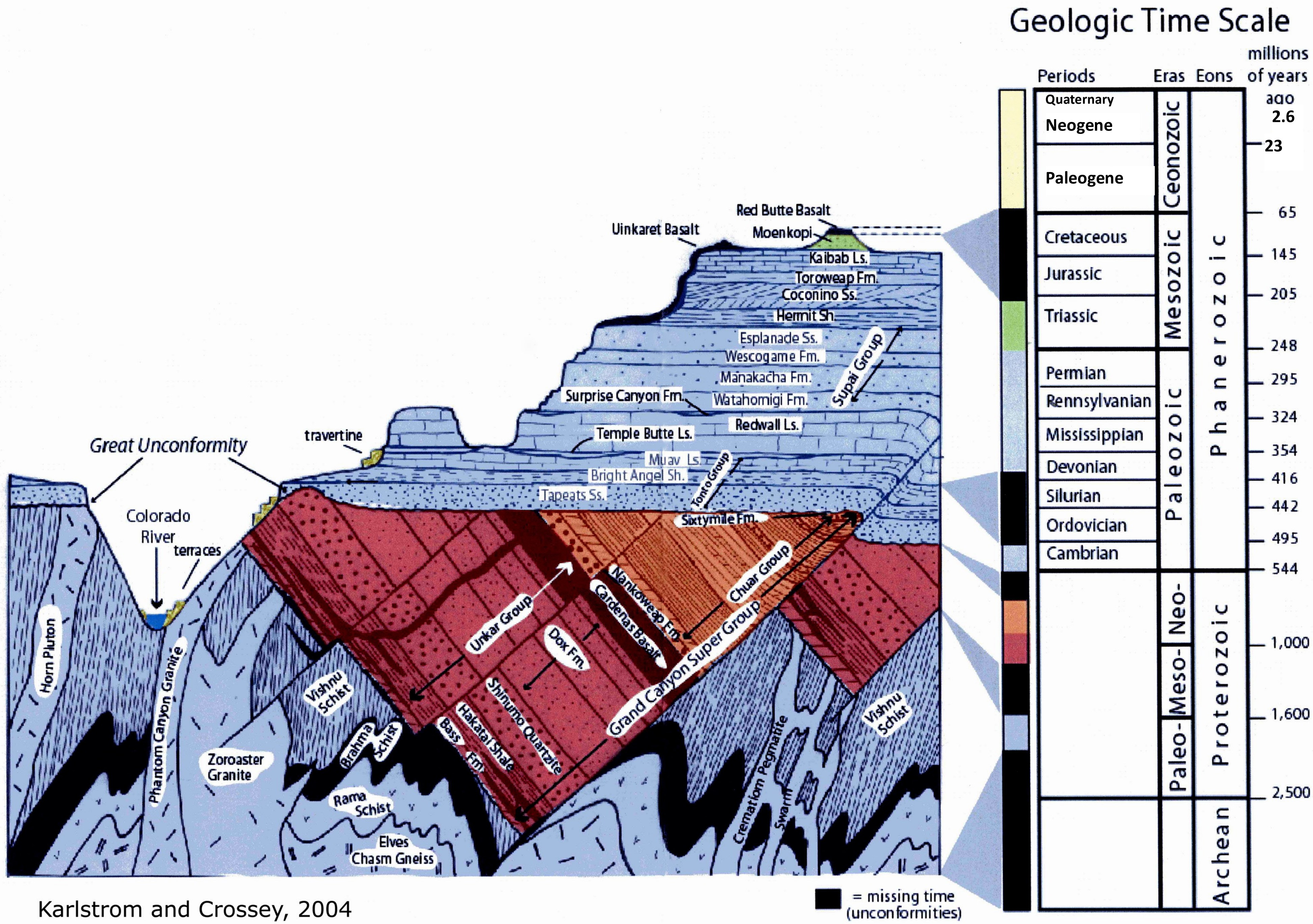
Table S1. Undergraduate student demographics from Fall 2016[1].

Characteristic	University Percentage	College Percentage	Department Percentage
Men	50.6%	43.1%	60.0%
Women	49.4%	56.9%	40.0%
American Indian	1.2%	1.6%	2.2%
Asian American	5.8%	5.7%	2.7%
African American	4.8%	5.5%	1.4%
Hispanic	21.3%	21.1%	16.9%
Pacific Islander	0.3%	0.3%	0.5%
White	54.6%	55.3%	64.1%
Two or more races	4.1%	4.5%	6.7%
Race/ethnicity unknown	0.6%	0.6%	0.2%
International	7.7%	5.8%	5.3%

[1] Data from University Office of Institutional Analysis

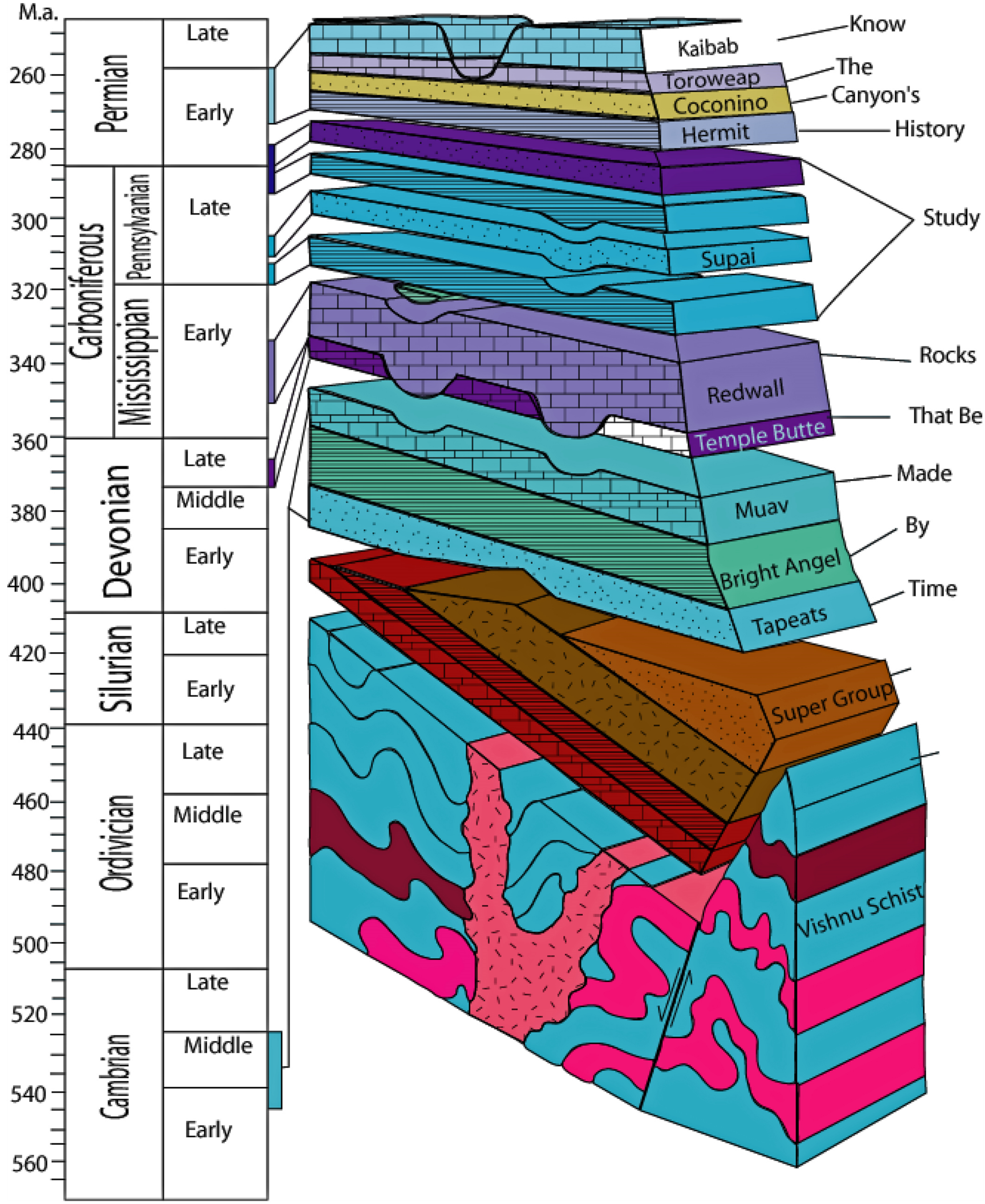
ipFT Guided Inquiry Worksheet





Karlstrom and Crossey, 2004

Geologic Time



YOUR NAME

Geological Field Trip to Grand Canyon National Park

WORKSHEET FOR CREDIT

Answer all of these questions based on what you observe at Yavapai Geology Museum and on the Trail of Time, and ***hand your completed worksheet in*** to the instructor ***at the end of the Trail of Time hike.***

Yavapai Geology Museum

1. How deep, how wide, and how long is Grand Canyon?

2. What is the elevation of the South Rim (where you are) compared to the elevation of the North Rim (list both elevations)?

3. Name two famous Grand Canyon geologists.

4. In this museum the geological history of Grand Canyon is subdivided into four intervals, each represented by an exhibit. List the titles of all four subdivisions:

5. Look at the geological cross-section and match the names of the rock units to the words in the mnemonic for Grand Canyon stratigraphy:

Know	
The	
Canyon's	
History;	
Study	
Rocks	
That Be	
Made	
By	
Time	

Trail of Time

6. About how many steps would you need to walk to reach the California coast from the start of this Trail?

7. Find the marker on the Million Year Trail corresponding to your age. Which one is it?

8. At least how many Native American tribes think of Grand Canyon as part of their homeland?

9. What was the climate at Grand Canyon like 20,000 years ago?

10. About when did the most recent volcanic eruptions in the western Grand Canyon occur?

11. Examine the transition between the Million Year Trail and the main Trail of Time (also called the Deep Time Trail). Summarize what you make of this part of the Trail—what were the Trail of Time designers trying to get across to the public?

As you walk the **Deep Time Trail**, keep track of the wayside rock exhibits that are most appealing to you. On the back of this worksheet, name and describe the rock(s), list any interesting features of the rock(s), and note why you liked these particular exhibits.

---

12. Walk the first six markers of the Deep Time Trail. What is the significance of these first six steps?

13. What had to happen to the Colorado Plateau before Grand Canyon could be carved out?

14. Why are there no dinosaur fossils found at Grand Canyon today?

15. What is the name of the top layer (rock unit) on the South Rim, and how old is it?

16. Spot the three Grand Canyon rock layers that record the Cambrian "explosion." What are they?

17. This particular sequence of three Cambrian rock units represents what kind of geological change?

18. Find the Great Unconformity deep in Grand Canyon. What do unconformities like the Great Unconformity represent?

19. How many missing years are represented by the Great Unconformity?

20. Who are the two people depicted in the Supergroup wayside panel at 1,160 million years ago on the Trail of Time?

21. Why are the layers of the Grand Canyon Supergroup tilted?

22. Between the marker for 1,200 million years ago and the marker for 1,662 million years ago on the Deep Time Trail, there is only one wayside rock unit displayed. Why are there so few rocks displayed on this stretch of the Deep Time Trail?

23. How were the Vishnu basement rocks formed, and over what time interval?

24. How much of the age of the Earth is represented by the age of the oldest rock exposed at Grand Canyon?

25. Our hike ends at Grand Canyon Village, but the Trail of Time continues beyond the Village and out to a marker corresponding to the age of the Earth. How far (either in meters or kilometers) must this marker be from the start of the Deep Time Trail?

iVFT Guided Inquiry Worksheet

Virtual Field Trip to Grand Canyon National Park
FIELD TRIP WORKSHEET FOR CREDIT

Answer all of these questions based on what you observe on the **Immersive Virtual Field Trip (iVFT) to Grand Canyon** (Free Exploration), and ***hand your completed worksheet in*** at the start of class on **Tuesday**

Entering the iVFT

When you enter this iVFT, you will find yourself in a place called **The Granaries**, where Nankoweap Canyon (a tributary) enters Marble Canyon (the upper main stem of Grand Canyon).

Notice that at the *upper right corner* of the window, there are five circular buttons. ***Click*** on the button marked with a question mark **(?)** and take the brief **tutorial** on how to navigate inside the iVFT environment.

Once you have learned how to use the simple navigation tools, you are welcome to explore as freely as you wish at every virtual stop we will take along Grand Canyon. Move your mouse around for the 360-degree spherical views (including up and down) and click on as many photo and video icons as you would like, anywhere that you go…Grand Canyon is yours to (virtually) explore!

Follow the instructions below in order to be **guided** along the iVFT to visit different geologically important places (“stops”) in Grand Canyon. At each stop, you will need to do some exploration in order to answer the questions posed to you. Be sure to ***answer all 12 questions*** and record all of your answers on this Worksheet.

You will need to submit this completed Worksheet in class on Tuesday to receive full credit for this iVFT.

Are you ready to take the iVFT…?

The Granaries

Here we are already 50 miles downstream on the Colorado River from the start of the Canyon.

If you'd like, jump down to **Granaries Beach Camp** to see what it is like to camp alongside the Colorado River for geological research and education. But you need to jump back up to **The Granaries** before you can answer this:

1. Click on the Video icon for Canyon Layers. What are the lowermost and uppermost rock units in the Canyon here at Nankoweap Canyon?

Click on the Video icon for On River (located down on the river) and enjoy a little taste of white-water rafting! Then jump down to

Mile 60-Sixty mile rapids

2. What rock unit are we in at this location, and how old is it?
3. What kind of fossils are preserved in the rock at this place?
4. These fossils record part of a major event in the evolution of life on Earth. What was that event?

Now jump down to **Mile 62-Little Colorado River Confluence**

5. Why is the water in the Little Colorado River so blue?

Jump down to **Mile 65-Carbon Creek Camp,** and let's take a hike up Carbon Canyon, a beautiful tributary slot canyon. Do this by first jumping to **Carbon Canyon-Slot Canyon** (wow! Cool, huh?) and then again to

Butte Fault

6. Here, the flat-lying beds of the Tapeats Sandstone have been folded up on their sides. What kind of fold is this? Why is the fold here?

Now we'll hike deeper into the arid and rarely visited Chuar Valley by jumping to **Lava Chuar hill hike**. Look around a little at the beauty, then jump again to

Lava Chuar Canyon Stromatolites

7. What rock set are we in here? When were these rocks deposited?
8. How were these stromatolites formed?

Jump to **Mile 66-Lava Canyon (Chuar) Rapid Camp** to rejoin our expedition on the river. Jump again to **Mile 75-Seventy five mile creek slot canyon**, and then to

Mile 81-Vishnu Creek Camp

Do you notice that we've camped among some very different kinds of rocks here at mile 81? Cross the river by jumping to

Vishnu Creek

Find the Video icon for Rock descriptions to answer the next question:

9. What two types of rock are exposed in this narrow canyon? About how old are these rocks?

Now jump back to **Mile 81-Vishnu Creek camp**.

10. Why did John Wesley Powell call these basement rocks "the dreaded granite?"
11. How deep in the crust were these rocks originally formed?

Continue on down river; jump to **Mile 85-Zoroaster Granite Rapid**

12. What is special about granite pegmatite?

You have traveled many miles and several days into the depths of Grand Canyon, and had an opportunity to investigate the three main groups of rock that are exposed here. Next, you will explore a specific place in the Canyon a little farther downriver, in much more detail.

Feel free to explore more of Grand Canyon via the iVFT interface if you have the time and inclination, but otherwise you may exit the iVFT and proceed to the next step: the online **Blacktail Canyon Lab**. The link is posted on Blackboard.

Remember to ***bring this completed Worksheet to class*** on Tuesday for full extra credit!

Your name:

For 10 points class credit

From memory only—***not*** from your notes, textbook, or any other sources, and with help from nobody else—make a sketch of the **Great Unconformity** as it is exposed deep in Grand Canyon. Make your sketch in the space beneath the dashed line below. Include **as much detail** as you can remember about the Great Unconformity, and **label everything** that you include in your sketch.

You will ***not*** be graded on artistic ability, but you should try to fill up the entire space with your sketch, and draw and write your labels as legibly as you can.

Make this sketch ***on your own***—do not consult or work with anyone else.

GREAT UNCONFORMITY CONCEPT SKETCH RUBRIC **IDENTIFIER**: ________________

VISUALIZATION (Does it look like the Great Unconformity?)

Contact (2 points)
contact is distinct and clearly drawn (1) ________
contact is distinct and clearly drawn (1) ________

Rock Units (2 points)
rock unit(s) drawn above contact (1) ________
rock unit(s) drawn below contact (1) ________

Rock Unit(s) Above Contact (2 points)
rocks above contact are layered (1) ________
rocks above contact are layered (1) ________

Rock Unit(s) Below Contact (2 points)
rocks below contact are foliated, denoted by lines (1) ________
foliation is near vertical, denoted by vertical lines (1) ________

VISUALIZATION SCORE (8 points) ________

INTERPRETATION (Does it portray the geology of the Great Unconformity?)

Contact (1 point)
contact is labeled as Great Unconformity (1) ________

Rock Units (2 points)
rock unit(s) above contact labeled as sedimentary (1) ________
rock unit(s) below contact labeled as metamorphic (1) ________

Sedimentary Rocks Above Contact (2 points)
clastic texture denoted by circles, stipples, etc. (1) ________
sedimentary unit(s) labeled as Tapeats Sandstone (1) ________

Metamorphic Rocks Below Contact (1 point)
metamorphic unit(s) labeled as basement rock* (1) ________

Additional Features (3 points)
Great Unconformity labeled as nonconformity (1) ________
major age difference noted between upper & lower units (1) ________
age difference of 1840 Ma versus 525 Ma noted (1) ________

INTERPRETATION SCORE (9 points) ________

***accept Basement, Elves Chasm Gneiss, Vishnu Schist, Rama or Brahma Schist

VISUALIZATION SCORE (8 points) ________
INTERPRETATION SCORE (9 points) ________

TOTAL SCORE (17 points) ________

Pre-Trip Survey (ipFT and iVFT)

Before you take either the Field Trip or Virtual Field Trip to Grand Canyon, please fully complete this **2-**page survey and turn it in.

Part 1

This survey consists of a number of words that describe different feelings and emotions. Read each item and then circle the number from the scale below next to each word. Indicate to what extent you feel this way ***in anticipation of the trip you will participate in.***

	1 Very slightly or not at all	2 A little	3 Moderately	4 Quite a bit	5 Extremely
Interested	1	2	3	4	5
Distracted	1	2	3	4	5
Excited	1	2	3	4	5
Bored	1	2	3	4	5
Enthusiastic	1	2	3	4	5
Confused	1	2	3	4	5
Inspired	1	2	3	4	5
Passive	1	2	3	4	5
Attentive	1	2	3	4	5
Overwhelmed	1	2	3	4	5
Active	1	2	3	4	5
Unfocused	1	2	3	4	5
Curious	1	2	3	4	5
Uncomfortable	1	2	3	4	5
	1 Very slightly or not at all	2 A little	3 Moderately	4 Quite a bit	5 Extremely

Part 2

Please answer each of these questions as they pertain to you personally today, and in as much detail as possible. Don't worry too much about precise spelling or grammar, but please try to write legibly so we can understand your responses! Feel free to continue writing on the blank side of the page if you need more room.

1. What are *at least* ***two*** *things* that you **already know** about the geology of Grand Canyon? (Feel free to list more than two!)

2. What are *at least* ***two*** *things* you would **like to know** about the geology of Grand Canyon? (Feel free to list more than two!)

Post-Trip Survey (ipFT)

After you have completed the Trail of Time hike at Grand Canyon, please fully complete this **3-page survey** and **turn it in as soon as possible.**

Part 1
This survey consists of a number of words that describe different feelings and emotions. Read each item and then circle the number from the scale below next to each word. Indicate to what extent you feel or felt this way ***after the hike.***

	1 Very slightly or not at all	2 A little	3 Moderately	4 Quite a bit	5 Extremely
Interested	1	2	3	4	5
Distracted	1	2	3	4	5
Excited	1	2	3	4	5
Bored	1	2	3	4	5
Enthusiastic	1	2	3	4	5
Confused	1	2	3	4	5
Inspired	1	2	3	4	5
Passive	1	2	3	4	5
Attentive	1	2	3	4	5
Overwhelmed	1	2	3	4	5
Active	1	2	3	4	5
Unfocused	1	2	3	4	5
Curious	1	2	3	4	5
Uncomfortable	1	2	3	4	5
	1 Very slightly or not at all	2 A little	3 Moderately	4 Quite a bit	5 Extremely

Part 2

Please answer each of these questions as they pertain to you personally today, and in as much detail as possible. Don't worry too much about precise spelling or grammar, but please try to write legibly so we can understand your responses! Feel free to continue writing on the blank side of the page if you need more room.

1. Was this your first visit to Grand Canyon? If not, please briefly describe any previous visits you had.

2. Please list and describe any factors that helped you learn Grand Canyon geology today.

3. Please list and describe any factors that made it difficult for you to learn Grand Canyon geology today.

4. What are the two most important things you learned about the geology of Grand Canyon today?

5. Can you articulate any misconceptions you had, either about the geology of Grand Canyon, or geology in general, that were cleared up after this visit?

6. What are *at least **two** things* you would like to know more about after visiting Grand Canyon today? (Feel free to list more than two!)

Post-Trip Survey (iVFT)

After you have completed the Grand Canyon Virtual Field Trip, please print out and fully complete this 3-page survey, and turn it in at the start of class on Tuesday.

Part 1

This survey consists of a number of words that describe different feelings and emotions. Read each item and then circle the number from the scale below next to each word. Indicate to what extent you feel or felt this way **right after completing the Virtual Field Trip**.

	1 Very slightly or not at all	2 A little	3 Moderately	4 Quite a bit	5 Extremely
Interested	1	2	3	4	5
Distracted	1	2	3	4	5
Excited	1	2	3	4	5
Bored	1	2	3	4	5
Enthusiastic	1	2	3	4	5
Confused	1	2	3	4	5
Inspired	1	2	3	4	5
Passive	1	2	3	4	5
Attentive	1	2	3	4	5
Overwhelmed	1	2	3	4	5
Active	1	2	3	4	5
Unfocused	1	2	3	4	5
Curious	1	2	3	4	5
Uncomfortable	1	2	3	4	5
	1 Very slightly or not at all	2 A little	3 Moderately	4 Quite a bit	5 Extremely

Part 2

Please answer each of these questions as they pertain to you personally today, and in as much detail as possible.

1. Have you been to Grand Canyon personally before? If so, please briefly describe any previous visits you had.

2. Having completed this Virtual Field Trip, are you ***more*** or ***less*** interested in visiting Grand Canyon in person? Please briefly explain your answer.

3. Please list and describe any factors that helped you learn Grand Canyon geology today.

4. Please list and describe any factors that made it difficult for you to learn Grand Canyon geology today.

5. What are the two most important things you learned about the geology of Grand Canyon today?

6. Can you articulate any misconceptions you had, either about the geology of Grand Canyon, or geology in general, that were cleared up after this virtual field trip?

7. What are *at least* ***two*** *things* you would like to know more about after virtually visiting Grand Canyon today? (Feel free to list more than two!)

PRE-HIKE IN-PERSON AND VIRTUAL QUESTION 1
What are at least two things you know about the geology of the Grand Canyon? Feel free to list more than two.

CODING RUBRIC

THEME 1: ROCKS & LAYERS
Student responded that they had knowledge of rocks, rock colors, strata, specific formations, striations, layers and groups. Specified knowledge of age of rocks.

THEME 2: HOW IT FORMED
Student responded that they had knowledge about the formation of the Grand Canyon via mechanisms such as erosion, wind, water, carving, uplift, incision. Student mentioned the Colorado River as a mechanism for how the canyon formed.

THEME 3: GEOLOGIC ATTRIBUTES
Student responded that they had knowledge about the Great Unconformity, missing layers, Colorado River, uranium, ancient seas, transgression/regression, caves, volcanism, lava dam, faults, dikes, length, karst, chert, mountain ranges, width, depth, location, age. Specified knowledge of age of Grand Canyon.

THEME 4: LIFE FORMS
Student responded that they had knowledge of plants, animals, and fossils.

THEME 5: HUMAN INTERACTIONS
Student responded that they had knowledge of Wesley Powell, explorers, scientists, scientific debates, native inhabitants, geoglyphs, hieroglyphs.

THEME 6: GRANDUER
Student responded that they the Grand Canyon was a wonder of the World, amazing, awesome, stunning, beautiful, inspiring, visible from space, landmark, national park, history.

PRE-HIKE IN-PERSON AND VIRTUAL QUESTION 2

What are at least two things you would like to know about the geology of the Grand Canyon? Feel free to list more than two.

CODING RUBRIC

THEME 1: ROCKS & LAYERS
Student responded that they want to know more about rocks, rock colors, minerals, strata, specific formations, striations, layers and groups.

THEME 2: HOW IT FORMED
Student responded that they want to know more about the formation of the Grand Canyon via mechanisms such as erosion, wind, water, carving, uplift, incision, river, mass wasting, sediment transport. Student mentions current and future processes – are the previous formation mechanisms currently at work and will they continue in the future.

THEME 3: GEOLOGIC ATTRIBUTES
Student responded that they want to know more about the Isis Temple, Elves Chasm, Horseshoe Bend, landmarks, Great Unconformity, missing layers, Colorado River, uranium, ancient seas, topography, transgression/regression, climate, caves, seismology, volcanism, lava dam, faults, dikes, length, karst, chert, mountain ranges, width, depth, location, age. Specified knowledge of age of Grand Canyon.

THEME 4: LIFE FORMS
Student responded that they want to know more about of plants, animals, dinosaurs, and fossils.

THEME 5: HUMAN INTERACTIONS
Student responded that they want to know more about Wesley Powell, explorers, scientists, scientific debates, native inhabitants, geoglyphs, hieroglyphs, tourism, Glen Canyon Dam, sightseeing.

THEME 6: GEOLOGIC TIME & CHANGE
Student responded that they want to know more about the canyon’s significance, importance uniqueness, the canyon’s future, the canyon’s past, history, time of formation, what the area was like before the formation of the canyon, missing time, how has water changed over time, change in plants and animals over time.

POST HIKE IN PERSON QUESTION 2
Please list and describe any factors that made it difficult for you to learn Grand Canyon Geology today.

CODING RUBRIC

THEME 1: TRAIL CONDITIONS
Student responded that it was cold, windy, crowded, loud, steps too short.

THEME 2: STUDENT EXPERIENCE
Student responded that they had trouble seeing, hearing, or understanding the professor. Student experienced cognitive overload or was bombarded with too much information.

THEME 3: FIELD TRIP CONTENT
Student responded that the FT content was dull or boring. Question packet interfered with learning. Too many rocks. Layers too difficult to discern.

THEME 4: PERSONAL CHALLENGES
Student responded that they were tired, sick, had to work, or didn't have enough time, distracted by photo ops, hungry, bathroom, or physically challenged. Students also responded that doing the field trip at the end of the semester was challenging.

THEME 5: NO DIFFICULTIES
Student responded that they had no difficulties.

POST HIKE VIRTUAL QUESTION 2

Please list and describe any factors that made it difficult for you to learn Grand Canyon Geology today.

CODING RUBRIC

THEME 1: TECHNICAL DIFFICULTIES

Student responded that they had trouble with computer, internet connection, browser, hardware, VFT freezing, slow load times, had to reload, no access to printer.

THEME 2: USER EXPERIENCE / INTERFACE

Student responded that they had trouble or were confused by the navigation. Icons were too small. Difficulty with mouse interaction with iVFT. Not sure what to look at. Students also responded that the interface was clunky, confusing, overwhelming. Sphericals constantly rotated. Student experienced cognitive overload or was bombarded with too much information. Student could not locate videos.

THEME 3: iVFT CONTENT

Student responded that the iVFT content was dry or boring. Photos were confusing, not relevant, low resolution or lacked information. Video content lacked info or was low resolution. The iVFT was too long or contained too many questions. The questions broke up the flow or were disruptive. Lack of graphs and diagrams. Informational videos appeared after wrong answer instead of before. Content too simple.

THEME 4: PERSONAL CHALLENGES

Student responded that they were tired, sick, had to work, or didn't have enough time. Students also responded that doing the assignment on a weekend was challenging. Student responded that they were distracted due to things going on around them, their cell phone, being home, or by being on the internet. Not there in person.

THEME 5: NO DIFFICULTIES

Student responded that they had no difficulties.

POST HIKE IN PERSON QUESTION 3
Please list and describe any factors that helped you learn Grand Canyon Geology today.

CODING RUBRIC

THEME 1: TRAIL CONDITIONS
Student responded that it was warm, good weather, clear, or good visibility.

THEME 2: TRAIL OF TIME
Student responded specifically about the Trail of Time or its components such as wayside panels, signs, photos, rocks, samples, trail markers or the Museum.

THEME 3: INSTRUCTOR & STUDENT INTERACTION
Student responded that the instructor or guide was helpful, or that the instructor's previous lectures, background knowledge or learning aides provided by instructor such as mnemonics and scavenger hunt. Student also responded about cooperation between students, fellow students or friends.

THEME 4: BEING IN THE FIELD
Student responded that physically being there, seeing in person, experiencing the scale and visual contact were helpful.

POST HIKE VIRTUAL QUESTION 3
Please list and describe any factors that helped you learn Grand Canyon Geology today.

CODING RUBRIC

THEME 1: PERSONAL ENGAGEMENT
Student responded that they had an interest or background knowledge in geology and/or the Grand Canyon that supplemented the iVFT experience.

THEME 2: USER EXPERIENCE / INTERFACE
Student responded that the navigation was quick or easy. The experience was dynamic, immersive, organized or interactive.

THEME 3: iVFT CONTENT
Student responded specifically about the content – ie, videos, photos, 360 degree tours, questions, worksheets, drawings, labs, professor, guide. Student also responded that the iVFT content was fun, short, engaging, had depth.

POST HIKE IN-PERSON AND VIRTUAL QUESTION 4
What are the two most important things you learned about the geology of the Grand Canyon?

CODING RUBRIC

THEME 1: ROCKS & LAYERS
Student responded that they learned more about rocks, rock colors, minerals, strata, specific formations, striations, layers and groups.

THEME 2: HOW IT FORMED
Student responded that they learned more about the formation of the Grand Canyon via mechanisms such as erosion, wind, water, carving, uplift, incision, river, deposition, mass wasting, sediment transport. Student mentions current and future processes – are the previous formation mechanisms currently at work and will they continue in the future.

THEME 3: GEOLOGIC ATTRIBUTES
Student responded that they learned more about the Isis Temple, Elves Chasm, Horseshoe Bend, landmarks, Great Unconformity, missing layers, Blacktail Canyon, Colorado River, uranium, ancient seas, topography, transgression/regression, climate, caves, seismology, volcanism, lava dam, faults, dikes, length, karst, chert, mountain ranges, width, depth, location, age. Specified knowledge of age of Grand Canyon.

THEME 4: LIFE FORMS
Student responded that they learned more about of plants, animals, dinosaurs, and fossils.

THEME 5: HUMAN INTERACTIONS
Student responded that they learned more about Wesley Powell, explorers, scientists, scientific debates, native inhabitants, geoglyphs, hieroglyphs, tourism, Glen Canyon Dam, sightseeing.

THEME 6: GEOLOGIC TIME & CHANGE
Student responded that they learned more about the canyon's future, the canyon's past, history, time of formation, what the area was like before the formation of the canyon, missing time, how has water changed over time, change in plants and animals over time.

THEME 7: GRANDUER
Student responded that learned the Grand Canyon was a wonder of the World, amazing, awesome, stunning, beautiful, inspiring, visible from space, landmark, national park, history, significance, importance, uniqueness, sense of scale.

POST HIKE IN-PERSON AND VIRTUAL QUESTION 5
Can you articulate any misconceptions you had, either about the geology of the Grand Canyon, or geology in general, that were cleared up after this visit or virtual field trip?

CODING RUBRIC

THEME 1: NO MISCONCEPTIONS
Student responded that they had no misconceptions.

THEME 2: AGE OF CANYON & ROCKS
Student responded that they misunderstood the age of the Grand Canyon or the age of rocks.

THEME 3: GREAT UNCONFORMITY
Student responded that they misunderstood the Great Unconformity, missing rock, missing layers, missing time, or lack of dinosaur fossils.

THEME 4: COLORADO RIVER
Student responded that they misunderstood the Colorado River, its power, its role.

THEME 5: FORMATION
Student responded that they misunderstood how the Grand Canyon was formed, the order of formation, the timeline of formation, the size, and elements of formation such as faults, contacts, volcanism, transgression/regression, and life.

THEME 6: ROCK TYPES & LAYERS
Student responded that they misunderstood rock types, rock groups, layers, composition.

THEME 7: GEOLOGIC TIME
Student responded that they misunderstood geologic time, deep time, time scales.

THEME 8: SIGNIFICANCE
Student responded that they misunderstood the significance of the Grand Canyon in terms of history, tourism, sense of place, scientific importance.

POST HIKE IN-PERSON AND VIRTUAL QUESTION 6

What are at least two things you would like to know more about after virtually/physically visiting the Grand Canyon today? Feel free to list more than two.

CODING RUBRIC

THEME 1: ROCKS & LAYERS

Student responded that they want to know more about rocks, rock colors, minerals, strata, specific formations, striations, layers and groups.

THEME 2: HOW IT FORMED

Student responded that they want to know more about the formation of the Grand Canyon via mechanisms such as erosion, wind, water, carving, uplift, incision, river, deposition, mass wasting, sediment transport. Student mentions current and future processes – are the previous formation mechanisms currently at work and will they continue in the future.

THEME 3: GEOLOGIC ATTRIBUTES

Student responded that they want to know more about the Isis Temple, Elves Chasm, Horseshoe Bend, landmarks, Great Unconformity, missing layers, Blacktail Canyon, Colorado River, uranium, ancient seas, topography, transgression/regression, climate, caves, seismology, tectonics, volcanism, lava dam, faults, dikes, length, karst, chert, mountain ranges, width, depth, location, age. Specified knowledge of age of Grand Canyon.

THEME 4: LIFE FORMS

Student responded that they want to know more about of plants, animals, dinosaurs, and fossils.

THEME 5: HUMAN INTERACTIONS

Student responded that they want to know more about Wesley Powell, explorers, science, study, scientists, scientific debates, native inhabitants, geoglyphs, hieroglyphs, ruins, history of exploration, history of study.

THEME 6: GEOLOGIC TIME & CHANGE

Student responded that they want to know more about the canyon’s future, the canyon’s past, history, time of formation, what the area was like before the formation of the canyon, missing time, how has water changed over time, change in plants and animals over time.

THEME 7: TOURISM & EXPLORATION

Student responded that they want to know more about tourism, visiting the Grand Canyon, hiking, camping, kayaking, rafting.