The Mid Atlantic Appalachian Orogen Traverse: A Comparison of Virtual and On-Location Field-Based Capstone Experiences

Steven Whitmeyer[1], Lynn Fichter[1], Anita Marshall[2], Hannah Liddle[1]

[1]Department of Geology and Environmental Science, James Madison University, Harrisonburg, VA, 22807
[2]Department of Geological Sciences, University of Florida, Gainesville, FL, 32611-2120

Corresponding author email: whitmesj@jmu.edu

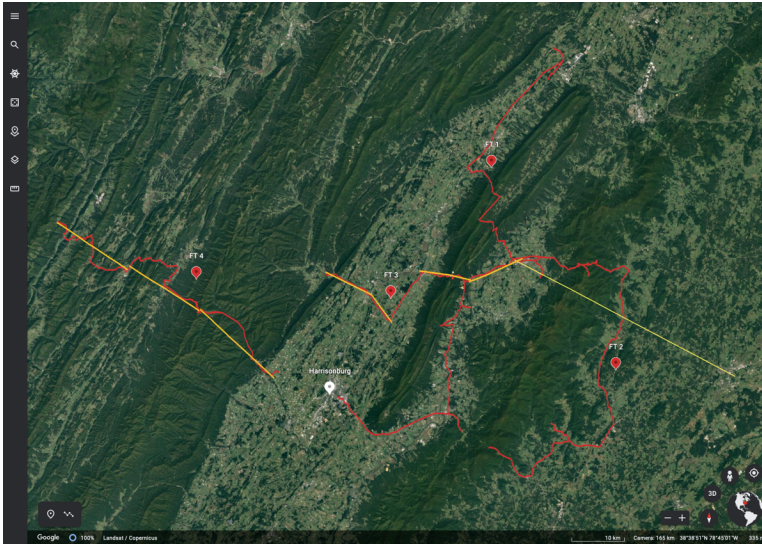
Abstract

The Stratigraphy, Structure, Tectonics (SST) course at James Madison University incorporates a capstone project that traverses the Mid Atlantic region of the Appalachian Orogen and includes several all-day field trips. In the Fall 2020 semester, the SST field trips transitioned to a virtual format, due to restrictions from the COVID pandemic. The virtual field trip projects were developed in web-based Google Earth, and incorporated other supplemental PowerPoint and PDF files. In order to evaluate the effectiveness of the virtual field experiences in comparison with traditional on-location field trips, an online survey was sent to SST students that took the course virtually in Fall 2020 and to students that took the course in-person in previous years. Instructors and students alike recognized that some aspects of on-location field learning, especially those with a tactile component, were not possible or effective in virtual field experiences. However, students recognized the value of virtual field experiences for reviewing and revisiting outcrops, as well as noting the improved access to virtual outcrops for students with disabilities, and the generally more inclusive experience of virtual field trips. Students highlighted the potential benefits for hybrid field experiences that incorporate both on-location outcrop investigations and virtual field trips, which is the preferred model for SST field experiences in Fall 2021 and into the future.

1. Introduction

On-location field trips and field experiences are a traditional component of undergraduate geoscience curricula. However, the onset of the COVID-19 pandemic in early 2020 resulted in quarantine restrictions that inhibited on-location fieldwork and field-based educational experiences for a substantial period of time. This left many geoscience departments scrambling to find alternative field experiences for courses that traditionally incorporated field-oriented educational components (e.g. Bond and Cawood, 2021; Bosch, 2021; Gregory et al., 2021; Quigley, 2021; Rotzien et al., 2021.) In many departments, alternatives to on-location field trips focused on virtual field experiences (VFEs), where geologic content and concepts that traditionally focused on physical outcrops were delivered online using an assortment of digital platforms. However, with the transition to virtual field experiences it is not clear how effective VFEs are in comparison to on-locations field trips, nor is it apparent how student learning is impacted. In this contribution we document how a series of on location field trips were migrated to VFEs, and we present preliminary data from instructors and students on the effectiveness of VFEs in comparison with on-location field experiences.

The necessity for transitioning undergraduate field experiences to virtual formats due to pandemic restrictions led to a grassroots effort by geoscience educators to assemble examples of virtual field experiences in a publicly accessible web portal for use by the community (Egger et al., 2021.) The National Association of Geoscience Teachers (NAGT) Teach the Earth portal developed a new site, entitled "Teaching With

53 Online Field Experiences," to host an array of virtual field experiences and teaching
54 modules. These range from introductory field trips to capstone projects, at virtual field
55 sites around the globe and beyond
56 (https://serc.carleton.edu/NAGTWorkshops/online_field/index.html). Like other
57 geoscience departments in the U.S. and Europe, the James Madison University (JMU)
58 Department of Geology and Environmental Science was significantly impacted by
59 pandemic-based field restrictions. JMU instructors for courses in Fall 2020 had to
60 rethink how to conduct the field components of their respective curricula in a virtual
61 environment, and looked to the NAGT Teaching with Online Field Experiences portal for
62 ideas and inspiration.
63   Among the JMU geoscience courses typically taught in the Fall semester is an
64 upper-level course, entitled Stratigraphy, Structure, Tectonics (or SST), that
65 incorporates basic principles of stratigraphy and basin analysis along with methods of
66 structural analysis, within the framework of models of the regional tectonic history and
67 the Wilson Cycle (Wilson, 1966; Burke and Dewey, 1974.) The course culminates with a
68 multi-week capstone project, where students spend 5 days in the field collecting
69 stratigraphic and structural data and interpret this data in the context of the Appalachian
70 Orogen in the Mid Atlantic region of western Virginia and eastern West Virginia (Fichter
71 et al., 2010; Figure 1.) This area is a classic example of relatively thin-skinned, fold and
72 thrust belt tectonics (e.g. Perry, 1978; Evans, 1989,) as well as displaying abundant
73 evidence of earlier depositional environments (e.g. Cooper and Cooper, 1945, Dennison
74 and Head,1975.) Most of the visible, outcrop-scale deformation in the region resulted
75 from the Alleghanian Orogeny (Bartholomew and Whitaker, 2010; Whitmeyer et al.,
76 2015,) although the Blue Ridge geologic province preserves deformation and fabrics
77 that derived from the Grenville orogenic cycle, along with younger Neo-Acadian high
78 strain zones (Bailey et al., 2006; Southworth et al., 2010.) In contrast, stratigraphic data
79 from the field trips provide evidence for earlier tectonic events, such as the Ordovician
80 Taconic Orogeny (e.g. Diecchio, 1993) and the Devonian Acadian Orogeny (e.g.
81 McClung et al., 2013.) Students use stratigraphic and structural field data that they
82 collect on the field trips to draft a series of interpretive cross sections across the Blue
83 Ridge and Valley and Ridge geologic provinces, and then synthesize their data and
84 interpretations in a report that describes the tectonic history of the region, from the
85 Mesoproterozoic Grenville orogeny through the Paleozoic assembly of Pangaea
86 (Whitmeyer and Fichter, 2019).

87
88 Figure 1. Screen image showing locations of web-based © Google Earth virtual
89 field trips in eastern West Virginia and western Virginia from the Mid Atlantic
90 Appalachian Orogen Traverse project; red lines indicate the paths of each field
91 trip (labeled FT1, FT2, FT3, FT4) and the yellow lines show the locations for
92 each cross section that students draft for the project.
93
94 The SST field trips that encompass the Mid Atlantic Appalachian Orogen
95 Traverse (MAAOT) project typically consist of five all-day trips on weekends, and focus
96 on roadcuts or easily accessible outcrops along a generally east-to-west transect,
97 roughly perpendicular to the regional strike (Figure 1.) Students work in teams to collect
98 lithologic and orientation data from each field trip site, and then spend time in
99 discussions with their colleagues and instructors to place the local outcrop data into a
100 regional tectonic context. In general, information from igneous and metamorphic rocks
101 provides data for the Grenville orogenic cycle, stratigraphic data provides the bulk of the
102 evidence for interpreting the Taconic and Acadian orogenies, and structural and
103 orientation data provides information for interpreting the Alleghanian orogeny. Some
104 specific field locations also provide data and information relevant to the breakup of the
105 Rodinia or the Pangaea supercontinents. The SST field trips are sequenced as follows:
106 Field Trip 1: This field trip functions as an introduction to Cambrian-Ordovician
107 sedimentary units of the Valley and Ridge geologic province, in the contexts of
108 the rifting of Rodinia, formation of the Iapetan divergent continental margin, and
109 the subsequent Taconic orogeny. Students are introduced to methods of
110 stratigraphic data collection, analysis, and principles of basin evolution.

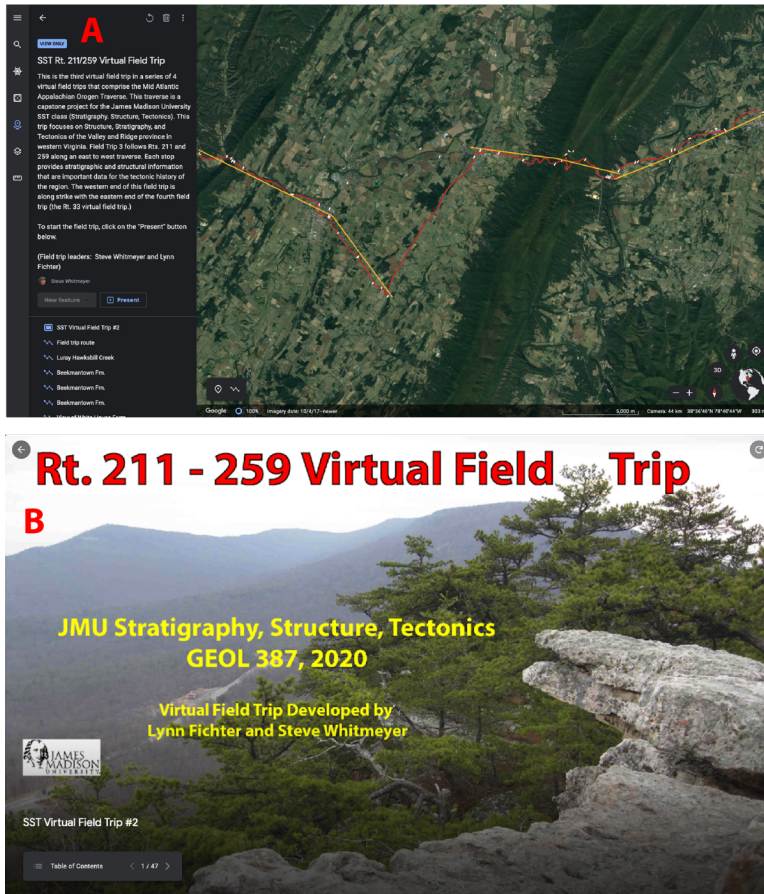
111   Field Trip 2: This field trip focuses on rocks of the Blue Ridge geologic province,
112   and students collect data on igneous and metamorphic composition and textures,
113   stratigraphic and sedimentological features, and structural/deformation features.
114   The tectonic context includes the Grenville orogeny, and two stages of the rifting
115   of Rodinia.
116   Field trip 3: This field trip progresses westward across the eastern part of the
117   Valley and Ridge geologic province, effectively linking with the northwestern end
118   of Field Trip 2. Students primarily collect data on stratigraphic features of
119   Ordovician (Taconic clastic wedge and subsequent orogenic calm) to Devonian
120   (Acadian clastic wedge and foreland basin) sedimentary rocks and later
121   structural/deformational features associated with the Alleghanian orogeny.
122   Field Trips 4 and 5: These field trips traverse across the middle and western
123   parts of the Valley and Ridge geologic province, ending at the Alleghany
124   deformational front in West Virginia. The eastern end of the traverse is along
125   strike with the western end of Field Trip 3. The traverse is divided into two field
126   trips, as the distance covered, and the number of stops visited, take up too much
127   time for a single day's field trip. Students again collect data on Paleozoic
128   stratigraphic and structural features, and evaluate depositional environments and
129   tectonic events from the Cambrian through the Carboniferous Periods.
130
131 On each of the first two field trips, student teams synthesize their field observations into
132 summaries of the geology and interpretations of the tectonic history of the region
133 traversed by each field trip. These tectonic synthesis reports are evaluated and
134 commented-on by instructors, and returned to the students as iterative drafts of the final
135 tectonic summary report that student teams produce at the end of the multi-week
136 project. Following the second and subsequent field trips, student teams draft interpretive
137 cross-sections along each field trip route, approximately perpendicular to the NNE-SSW
138 regional strike. Similar to the summary reports, these draft cross sections are each
139 evaluated and commented-on by professors, and returned to the students as iterative
140 drafts of the series of cross sections that collectively traverse the Appalachian orogen in
141 the Mid Atlantic region, which the students produce as part of their final project
142 deliverables (see Whitmeyer and Fichter, 2019 for more details on the project and
143 deliverables.) Through this iterative approach of collecting field data, drafting cross
144 section interpretations of the geology, and interpreting geologic data and models in a
145 summary report, students gain experience with data collection, interpretation, and
146 synthesis – key components of higher-order thinking in Bloom's taxonomy (Bloom et al.,
147 1956; Anderson et al., 2001.)
148
149
150

2. The Transition to Virtual Field Trips

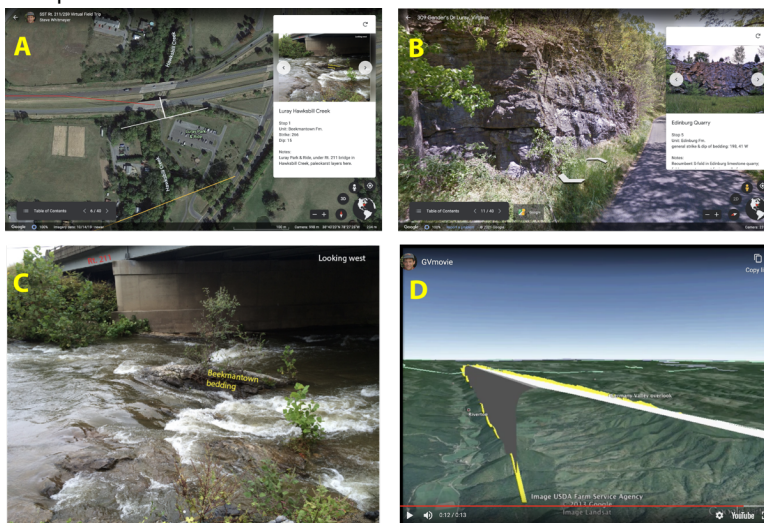
Due to the COVID restrictions on travel, field trips for the Fall 2020 SST course had to transition to a virtual format. There are several digital platforms that can be used to display spatial and geologic data in an interactive format (Google Earth, ArcGIS, Unity game engine, etc.); SST instructors used the web-based version of Google Earth to host virtual field trips for the MAAOT, primarily for its ease of use and near universal availability across a variety of computer hardware and mobile devices (see https://www.google.com/earth/versions/ for more information.) Each of the standard on-location SST field trips was redesigned as a Google Earth project that incorporated field trip sites in the general sequence that would be visited during a standard on-location field trip. The virtual Google Earth environment also facilitated the inclusion of extra field locations for which there would not normally be enough time to visit during a typical on-location weekend field trip. The four virtual field trips and associated materials that encompass the MAAOT are accessible via the links below:

      Field Trip 1: Stratigraphic Sequences of the Valley and Ridge Province
      Field Trip 2: Virtual Field Trip to the Blue Ridge Province, Central Virginia
      Field Trip 3: Rt. 211/259 transect
      Field Trip 4: Rt. 33 transect

The links above access field trip modules that are included on the NAGT Teaching with Online Field Experiences web portal (https://serc.carleton.edu/NAGTWorkshops/online_field/index.html). The modules follow the general format of other VFEs ob the web portal, starting with a summary of the exercise, followed by sections on the overall context of the field experience, the educational goals, the technology requirements, useful teaching notes and tips, and assessment strategies. Each module webpage includes a link to the relevant GE field trip along with exercise handouts, supplementary materials ("chalk talk" PowerPoint files), and other supporting documents.

      The web-based Google Earth (GE) platform used for these modules, though lacking some of the components of the downloadable desktop version of Google Earth Pro, has many features that make it ideal for hosting interactive virtual geology field trips. Chief among these is that web-based GE projects are hosted on the creator's Google Drive site, and thus can be easily shared with students via a standard browser link (e.g. SST Blue Ridge Field Trip.) Thus, in contrast to Google Earth Pro, web GE projects also can be interactively viewed on mobile devices. Web GE projects can be designed to sequentially highlight stops along a virtual field trip (Figure 2a) and can also include a full-screen title slide at the start of a presentation (Figure 2b) to introduce the project and orient the user.

189
190 Figure 2. Screen images of web-based © Google Earth virtual field trip 3 from the
191 Mid Atlantic Appalachian Orogen Traverse project; A. Overview of the SST Rt.
192 211/259 Virtual Field Trip project in © Google Earth; B. Title slide for the Rt. 211 -
193 259 Virtual Field Trip in © Google Earth
194

195 *2.1 Designing Virtual Field Trips in Web GE*
196 Field trip locations can be highlighted with standard GE Placemark pins or with multi-
197 node lines, such that strike and dip symbols can be drawn at an outcrop location,
198 thereby replicating features of a standard geologic map (Figure 3a.) Each slide (i.e. field
199 site) of a GE project can be tailored to show a zoomed in bird's eye or oblique view of
200 the location, or a zoomable and rotatable Street View image of the actual outcrop (if
201 Street View imagery is available for that location; Figure 3b.) Each slide can incorporate

202 a pop-up box with descriptive text and an image carousel that can sequentially display
203 up to eight images or videos. Clicking on an image in the box will display an enlarged
204 version of the image, which is useful for showing annotations and details of outcrop
205 features (e.g. Figure 3c.) Short explanatory videos can also be included in the image
206 carousel (e.g. Figure 3d,) as long as the videos are hosted on YouTube and made
207 available for public viewing. Details on how the virtual field trips were designed and
208 constructed in GE can be found in Whitmeyer and Dordevic (2019), which highlights a
209 virtual field trip across the Blue Ridge Province in Virginia (Field Trip 2 of the MAAOT)
210 as an example.

211
212 Figure 3. Screen images from web-based © Google Earth virtual field trips from
213 the Mid Atlantic Appalachian Orogen Traverse project; A. A virtual field trip site
214 that shows a birds eye view of the outcrop location with an oriented strike and dip
215 symbol drawn as a polyline in © Google Earth and a pop-up box with outcrop
216 information and slide carousel; B. A virtual field trip site that shows a zoomable
217 and rotatable Streetview image of the outcrop; C. An annotated photo of a field
218 site, shown as a enlarged image from the © Google Earth slide carousel from
219 Figure 3A; D. A model of a regional anticline displayed as a popup YouTube
220 movie from the © Google Earth slide carousel.
221
222 *2.2 Implementing Virtual Field Trips*
223 The SST virtual field trips were conducted in a format that replicated the organization of
224 an on-location field trip, minus the driving from stop to stop. Students and instructors
225 (field trip leaders) assembled online using the Zoom virtual meeting platform, and each
226 participant had access to virtual field trip materials, including the GE field trip project,

227 PowerPoint files of supplementary materials, and other handouts as PDF files.
228 Instructors used the screen sharing mode of Zoom to virtually visit each GE field trip
229 site, show outcrop photos and other imagery in GE, and at some locations, show more
230 detailed "chalk talks" of images and background concepts using PowerPoint. The
231 concept of "chalk talks" derives from on-location field trips, where a field trip leader
232 would use a chalk board or a whiteboard to illustrate specific features or concepts
233 relevant to a given field location. For on-location field trips, SST students were provided
234 with a packet of paper handouts that consisted of annotated images and theoretical
235 models as supporting materials for the "chalk talk" discussions. Given the GE restriction
236 of only 8 slides in the image carousel, for the virtual field trips "chalk talk" materials were
237 provided as supplementary PowerPoint and/or PDF files that included images,
238 diagrams, and models.
239   On virtual field trips in SST, interactive explanations, discussions, and queries
240 about the geology of each site were conducted on Zoom in a similar format to on-
241 location field stops. Short breaks were taken every couple of hours between stops to
242 avoid Zoom fatigue, recognizing that down times in on-location field trips that occurred
243 during travel from stop to stop do not occur during virtual field trips. A longer lunch
244 break was also included, again replicating a traditional field experience (minus the visit
245 to the grocery store or restaurant.) Overall, even with frequent breaks, each virtual field
246 trip typically took less time than its on-location counterpart, likely due to the elimination
247 of the time needed for travel along the field trip route.
248
249 **3. Experiences With Virtual Field Trips**
250 STEM educators recognize that teaching and learning in a virtual environment can be
251 dramatically different from in person interactions between instructors and students (e.g.
252 Humphrey and Wiles, 2021), although instructors and students often recognize the
253 value of virtual education environments (Mikropoulos and Natsis, 2021.) Challenges in
254 virtual education are apparent in situations where direct observations, interactive
255 discourse, and hypothesis testing are highlighted as essential components of field-
256 focused learning (Hurst, 1988; Mogk and Goodwin, 2012.) Kastens et al. (2009) note
257 the value of guided apprenticeship between field instructors and students, which can be
258 especially difficult to achieve in virtual field experiences that are designed for student-
259 centered inquiry (Jacobson et al., 2009; Mead et al., 2019.) In addition, aspects of
260 community building and student integration into a community of practice can be lacking
261 in virtual field experiences (Mogk and Goodwin, 2012; Race et al., 2021.) However,
262 Orion and Hofstein (1994) note the importance of limiting novelty space in field
263 experiences, which can be somewhat addressed with virtual introductions to learning in
264 the field. Considering these issues and challenges with online learning environments,
265 SST instructors were mindful of the need to incorporate community building activities,

266 include real-time observation and discussion of geologic features, and limit aspects of
267 unidirectional content delivery.
268
269 *3.1 Instructor Experiences with Virtual Field Trips*
270 With the change to virtual interactions with students, instructional approaches to field-
271 based teaching and learning were reconceptualized, starting with development of the
272 virtual field experiences. Experienced field instructors are aware that field work has its
273 own methods and procedures, very different from the classroom (Whitmeyer et al.,
274 2009; Mogk and Goodwin, 2012.) For virtual field trips the challenge was to create an
275 interactive learning experience for students within a virtual format with which they are
276 less familiar. The process of redesigning field trips for a virtual environment started with
277 instructors re-visiting outcrops and systematically and deliberately considering the
278 typical sequence of events, from exiting the vans, to investigating and discussing the
279 outcrop features, to returning to the vans. Several months of development were
280 necessary to create the MAAOT virtual field trips in web GE (as documented in
281 Whitmeyer and Dordevic, 2021,) and assemble associated supplemental materials.
282 Fortunately, the instructors had collected field photos and videos from several years of
283 visiting the field trip locations with previous SST classes, and many of these visual
284 materials were included in the GE field trips. Similarly, supporting diagrams and models
285 had been developed in previous years and were included with the virtual field modules
286 as supplementary PowerPoint and PDF files.
287   Examination of an outcrop on an SST field trip starts with the outcrop's location
288 and where it is situated within the regional geographic context. Constructing tectonic
289 interpretations requires data from many outcrops across a wide region, and thus it is
290 important for students to know the spatial relationships between the outcrops. Driving
291 from stop to stop in the course of an on-location field trip can help illustrate the
292 distances between outcrops. However, spatial relationships still can be a challenge, as
293 many students travel from stop to stop without keeping track of their geographic
294 locations. The GE component of a virtual field experience makes it easy to show the
295 location of an outcrop within a broader region, which helps students conceptualize the
296 regional geologic context.
297   Educational field experiences typically highlight hands-on observations,
298 measurements, and field-based interpretations. An important component of
299 observations at a real or virtual outcrop is recognizing and separating out stratigraphic
300 vs. structural features, metamorphic overprinting, weathering phenomena, etc.
301 (Compton, 1985; Coe, 2010.) Each of these is an important outcrop datum, but the
302 initial parsing of these features is an important component of SST. Outcrops are not
303 always examined and discussed with the same hierarchy or order of investigations;
304 sometimes structural analyses come first, sometimes stratigraphic features are
305 emphasized. Instructors in field settings have found it effective to ground their

306 instructional approach in iterative cycles of encouraging observation, followed by
307 interpretation, followed by subsequent rounds of more detailed observations and
308 interpretations (e.g. De Paor and Whitmeyer, 2009; Mogk and Goodwin, 2012.) Only
309 after students repeatedly have been encouraged to get as much information from each
310 outcrop as possible are they tasked with making bigger picture synthetic observations
311 and interpretations.
312   One of the challenges of virtual field trips is that what should be student inquiry-
313 centered "observe and discuss" interactions can easily become unidirectional "show and
314 tell" lecturing by field trip leaders. Without the ability to easily read faces or body
315 language, observe students working the outcrop, or hold impromptu discussions, it is
316 easy for instructors and students to become disconnected from what is ideally an
317 interactive field experience (e.g. Petcovic et al., 2014.) Recognizing the ease with which
318 they could lapse into "show and tell" mode (e.g. online classroom lectures via Zoom,)
319 the SST instructors deliberately encouraged interactive discourse among participants at
320 each field site, and depended on a willingness from participants to highlight when virtual
321 interactions and active participation were lacking. Taking the time to initiate discussions
322 is important, and the key is to keep interactive conversations going throughout a field
323 trip. As a field day progresses students generally get more comfortable with the
324 discourse, as long as an interactive discussion framework is initiated early in the trip.
325
326 *3.2 Structural Analyses on Virtual Field Trips*
327 Structural analyses on SST field trips initially focus on characterizing lithologies and
328 recognizing where in the stratigraphic sequence an outcrop is positioned, in addition to
329 knowing where the outcrop is located geographically. Secondly, students need to record
330 the orientations of planar fabrics, such as bedding or foliation, and recognize broad fold
331 patterns and geometries from changing dip amounts and alternating dip directions.
332 Thirdly, lineations and other outcrop-scale deformation fabrics (e.g. slickenlines,
333 asymmetric porphyroclasts, etc.) are important to recognize and measure, where
334 apparent.
335   The virtual field environment presents several challenges for collecting
336 structurally-related outcrop information and data. Identification of rock types and
337 differentiation of lithologic units can be difficult with static images. Replicating orientation
338 measurements online is a significant challenge, although virtual compasses do exist as
339 components of some virtual outcrop experiences (e.g. Masters et al., 2020,) and some
340 3D terrain models can be used for virtual measurements (e.g. Cawood et al., 2017;
341 Brush et al., 2018.) Our approaches to virtual field trips centered on providing outcrop
342 imagery at multiple scales and in different formats (e.g. static outcrop photos, dynamic
343 Street View images; Figure 4a,) often with annotations to highlight important features
344 (Figure 4b.) Instructors used this imagery during Zoom discussions to iteratively
345 encourage students to make ever more detailed observations of an outcrop, making

346 sure that students obtained the salient lithologic and structural information that would
347 aid in their subsequent tectonic interpretations.
348   Outcrop orientation measurements can be extremely difficult to facilitate in a
349 virtual environment, and the experience of using a virtual geologic compass is currently
350 ineffectual with a web-based platform like Google Earth. Thus, the approach in the
351 MAAOT field trips is to provide orientation data in the pop-up boxes associated with
352 stops that featured bedding, foliation, and/or lineation information (e.g. the text in the
353 pop-up boxes of Figures 3a, 3b, 4a.) This is clearly not the same pedagogical
354 experience for students as using a physical geologic compass (e.g. Brunton Pocket
355 Transit) to take their own measurements on an outcrop, but the instructors accepted
356 that this was not a skill that could be effectively replicated virtually.
357   Key deformation fabrics that are visible on an outcrop can be highlighted virtually
358 via images, and an advantage of the virtual environment is that photos can include
359 annotations that explain the relevant structural interpretations of a particular feature. For
360 example, ductily-deformed porphyroclasts that display asymmetry can be used to
361 determine the direction of movement that occurred during a ductile fault (shear zone)
362 (Passchier and Simpson, 1986.) Annotations on an outcrop photo can clearly
363 demonstrate to students the appropriate way to interpret these features, as with the
364 complex sigma porphyroclast in Figure 4c that displays a top-to-the-left sense of
365 movement. In addition, virtual images and animations can illustrate or model structural
366 features that are at a regional scale - much larger than can be viewed at a single
367 outcrop (e.g. the kilometer-scale anticline modeled in Figure 3d.) Instructors often
368 attempt to model these larger structures for students while on-location at a key outcrop
369 using verbal descriptions or hand waving, but they lack the ability to figuratively "step
370 back" and illustrate the bigger picture. The ability to take a regional view of large
371 features, and if desired display a model of them, is a distinct advantage of the virtual
372 environment.

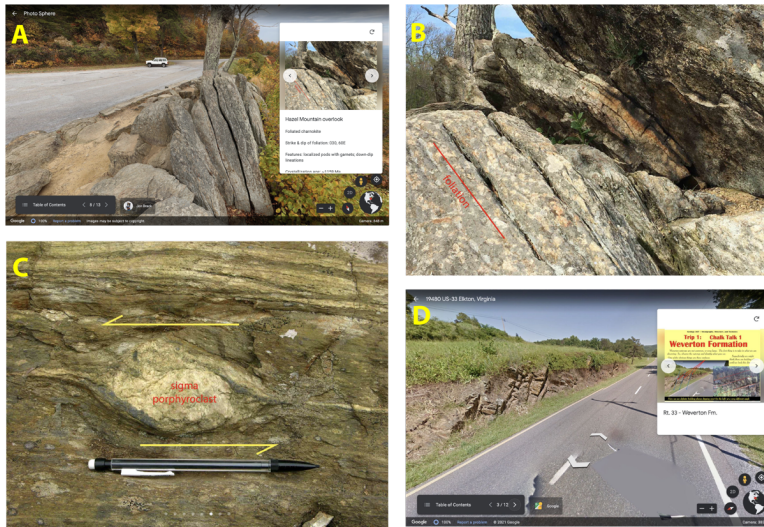



Figure 4. Screen images from web-based © Google Earth virtual field trips from the Mid Atlantic Appalachian Orogen Traverse project; A. A Street View image of the Hazel Mtn. Overlook site from FT2, positioned to look along strike of foliation; B. An annotated photo of the same outcrop as A., highlighting the foliation; C. An annotated photo of a complex sigma porphyroclast from the Garth Run site of FT2; D. A Street View image of the first field trip site of FT1 on Rt. 33 in western Virginia.

3.3 Stratigraphic Analysis and Basin Evolution on Virtual Field Trips

Field-based stratigraphy and basin analysis require somewhat different approaches from the analysis of structural features. Unlike tectonic structures (folds, faults, slickenlines, etc.,) which are often visible on an outcrop, tectonic basins are at a scale that is not apparent at a single outcrop. In addition, depositional environments are interpretations built on a hierarchy of observations, which can be challenging to discern. The goals of field-based stratigraphy and basin analysis are to use bottom-up empirical data to construct a tectonic basin interpretation (e.g. Allen and Allen, 2005) and to use theoretical first principles and models to make interpretations of outcrop observations (e.g. Van Wagoner et al., 1990; Van Wagoner, 1995.) The approaches to field-based stratigraphy and basin analysis in the SST course previously have been presented in detail (Fichter et al., 2010; Whitmeyer & Fichter, 2019.) The paragraphs that follow highlight how these approaches have been adjusted and modified for the virtual environment.

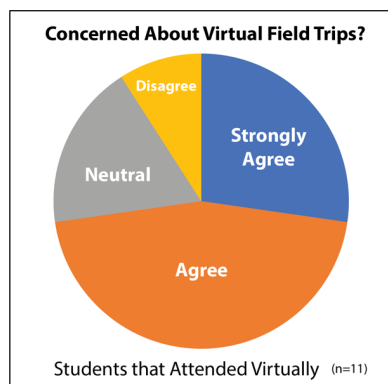
Theoretical principles and models of stratigraphy, sedimentation, and basin analysis (e.g. Coe et al., 2003; Posamentier and Walker, 2006; Xie and Heller, 2009)

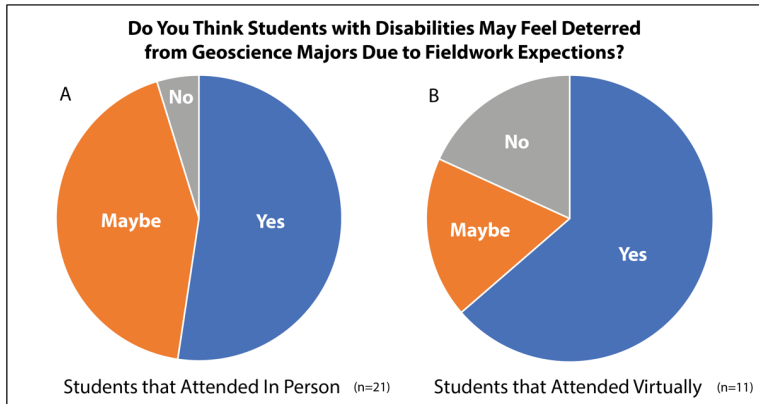
398   are developed in SST classroom lectures and discussions, but commonly these topics
399   have not been fully explored prior to the initial field trips in the MAAOT. In addition, the
400   practical field skills of recognizing and identifying sedimentary structures (e.g. trough,
401   planar, or hummocky cross stratification) and stratigraphic sequences (Bouma,
402   hummocky, point bar, etc.), and drawing strip logs are best learned through practice.
403   Concepts presented in the classroom are revisited and honed on the outcrop, via
404   iterative conversations. The main challenge in developing SST virtual field trips was to
405   reproduce these experiences in Zoom, using GE-based presentations and PowerPoint
406   "chalk talks".
407   Stratigraphic analyses at an outcrop start with observation at a variety of scales,
408   which can be facilitated by GE Street View imagery (Figure 4d,) such that students can
409   virtually walk past an outcrop, zoom in and out, and view it from different angles. At a
410   virtual field site, with or without Street View, this also necessitates student access to
411   many detailed and annotated outcrop photos. In an on-location field trip this observation
412   phase incorporates back and forth conversations between faculty and students, where
413   faculty prompt students with questions and hypotheses that necessitate integration
414   across scales of observation to build and refine a stratigraphic, basin analysis, and
415   tectonic story. Initial overviews are followed by detailed investigations that use
416   photographs of representative parts of an outcrop that include annotations to highlight
417   bedding, sedimentary structures, textures, etc. However, it is challenging for students to
418   learn to recognize stratigraphic features from a photograph. Thus, the resolution of the
419   photos is important to ensure that the salient features are clear and unambiguous,
420   which often necessitates multiple views of a feature. To facilitate this, the instructors
421   revisited many MAAOT outcrops prior to the start of the Fall 2020 semester, in order to
422   get high resolution pictures in the best lighting conditions and incorporate them in the
423   GE field trip sites and supplementary documents.
424   An outcrop-oriented synthesis activity for students encompasses drawing a strip
425   log, and in virtual environments this is accomplished by examining an outcrop photo or
426   sequence of photos if a lengthy exposure. The activity commences with a discussion of
427   the stratigraphic section under consideration (instructors obtained detailed images for
428   this purpose,) where students make preliminary observations and initate a dialogue
429   about what they observe. Students proceed to draw their own strip logs from a
430   combination of what they have observed and information they have developed via the
431   discussions. At this point during an on-location field trip students would lay their strip
432   logs down on the ground for group examination that include provocative discussion
433   prompts from instructors. This can be challenging to accomplish virtually, although an
434   approach used in SST was for students to hold their drawings up to their laptop or
435   mobile device cameras for viewing by the group. Students then redraft their strip logs,
436   progressing through as many iterations as are necessary, in order to build observational
437   and interpretive skills. This iterative approach can be time consuming on-location at an

438   outcrop, where environmental factors can impact productivity and morale. A virtual
439   setting facilitates an expanded timeframe for iterative discussions and analyses, which
440   may prove more effective for student learning.
441
442   *3.4 Synthesis Discussions on Virtual Field Trips*
443   Outcrop investigations for both stratigraphic and structural datasets progress
444   from observations through interpretations and culminate with tectonic syntheses,
445   becoming progressively more theoretical in focus. In an on-location field trip theoretical
446   interpretations are presented with posters ("chalk" boards) tacked to the sides of vans,
447   or as paper handouts. This can be problematic in bad weather, or in a large class where
448   students on the distant edges of the group have trouble seeing and hearing the
449   discussions. Virtual chalk talks on Zoom using PowerPoint slides obviates this -
450   everyone has the same access and opportunity to interact, without the distractions of
451   environmental factors. Virtual chalk talks have the facility to display detailed models that
452   were initially presented in classroom lectures to the relevant data that students just
453   examined on the outcrop. In the classroom the theoretical models likely didn't have
454   much relevance to the students, but because the virtual chalk talks can incorporate high
455   quality illustrations for discussions at the virtual outcrop, learning can be timely and
456   relevant. As stops accumulate throughout a field day the theoretical models keep
457   reappearing and building on each other. Thus, the models and concepts become
458   familiar and increasingly more relevant to the students, with the added cognitive
459   stimulus provided by associating the theoretical models with tangible data from outcrops
460   and sequences of field trip locations.
461
462   **4. Survey of Student Experiences with In-Person vs. Virtual Educational Formats**
463   Historically, the geosciences have been largely field-focused (e.g. Himus and Sweeting,
464   1955), and undergraduate curricula have traditionally incorporated a significant
465   component of field-based learning (Whitmeyer et al., 2009; Mogk and Goodwin, 2012.)
466   This field emphasis has been used for many years to recruit students to the discipline
467   that have an affinity for, and appreciation of, the outdoor environment. An ongoing
468   challenge in geoscience disciplines is to increase access and inclusion for all students
469   (Bernard and Cooperdock, 2018; Ali et al., 2021; among many others,) yet field-based
470   learning experiences can present a significant barrier to those efforts (e.g. Clancy et al.,
471   2014; Giles et al., 2020.) Disability access to field environments is a growing concern
472   among geoscientists and geoscience departments (Carabajal et al., 2017; Whitmeyer et
473   al., 2020,) especially with regards to recruitment and retention of students in
474   geoscience-related fields (Baber et al., 2010; LaDue and Pacheco, 2013; Stokes et al,
475   2015; Pickrell, 2020.) Virtual field experiences are one potential solution to inaccessible
476   field experiences, but little data exists on academic growth during virtual field
477   experiences and how that growth compares to in-person field learning.

478 	With these things in mind, an online survey was developed to collect data from
479 	undergraduate SST students on their perceptions of both virtual and online field
480 	experiences, as well as self-evaluations of their academic growth in each of those
481 	environments. The survey was sent to SST students that had participated in the virtual
482 	field trips for the MAAOT in Fall 2020, as well as to SST students from the 5 previous
483 	years that had participated in traditional on-location field trips during the Fall semesters.
484 	The instructors for the SST course and field trips were the same across all years of the
485 	survey. The survey included questions that addressed student preferences for in-person
486 	or virtual field experiences, self-evaluations of academic growth across a range of topics
487 	relevant to the SST course, and questions that addressed student disabilities in the
488 	context of field access and inclusivity. Details of survey questions are available in
489 	Appendix A.
490 	Data were collected anonymously via an online survey instrument using
491 	Survey123 through ArcGIS Online. In accordance with guidelines from the Institutional
492 	Review Board (IRB) at JMU, survey data was anonymized to remove any information
493 	that could facilitate identification of individual respondents, and no demographic data
494 	was collected. All survey respondents had the option to disallow the use of their
495 	responses to any question in the survey. Survey data was aggregated across all
496 	responses, or aggregated within two groups: students that participated in virtual field
497 	experiences, and students that participated in on-location field experiences. These
498 	methodologies for data collection, analysis, and reporting are in accordance with the
499 	ethical policies at JMU, and the methods were approved by JMU's IRB. Responses to
500 	the survey were received from 11 students that participated in virtual field experiences
501 	in the Fall 2020 semester, and 21 students that participated in on-location field trips
502 	from the SST course across 5 previous years. The responses were organized into three
503 	themes: preferences for in-person vs. virtual field experiences, disability and field
504 	access, and a comparison of academic growth between in-person and virtual field
505 	learning.
506
507 	*4.1 Student Preferences for Virtual vs. In Person Learning Experiences*
508 	Prior to Fall 2020, the lectures, labs, and field trips in the SST course were all
509 	conducted in-person and on-location in the field. None of the students that took SST
510 	prior to Fall 2020 had experience with virtual classes or virtual field trips, outside of the
511 	occasional use of a virtual platform like Google Earth to illustrate regional to global scale
512 	topographic or geologic phenomena. Not surprisingly, students that took the SST
513 	course prior to 2020 did not indicate a preference for virtual learning, although a few
514 	students recognized the potential value of hybrid experiences that combined both virtual
515 	and on-location field learning (Figure 5a.)

531   Figure 5. Charts of learning style preferences from student survey; A. Learning
532   style preferences from students that attended SST classes and field trips in
533   person, with no preferences for virtual learning style indicated; B. Learning style
534   preferences from students that attended SST classes and field trips virtually, with
535   a greater preference for hybrid and virtual learning styles.
536

537 Some students that experienced virtual learning and virtual field experiences in the Fall
538 2020 SST course likewise indicated a preference for in person experiences; however, a
539 majority of these students indicated a preference for hybrid or virtual learning
540 experiences (Figure 5b.) In addition, most of the Fall 2020 students that attended SST
541 as a virtual class indicated that they had some concerns about virtual field trips prior to
542 experiencing them (Figure 6.) However, Figure 5b suggests that many of these students
543 gained an appreciation for virtual field experiences by the end of the course.
544

545
546   Figure 6. Chart of responses from students that attended SST virtually on
547   whether they were concerned about participating in field trips virtually.

548
549   For many students virtual field experiences were not as satisfying as being
550 physically at an outcrop, as noted in the following response from a student that attended
551 SST virtually:
552   *"While I feel as though I have missed out on an important [field] experience by*
553   *taking SST online…"*
554 However, that response continues with:
555   *"...I feel I learned more than I would have because of my ability to re-watch*
556   *lectures and go back to the [virtual] field trips."*
557 This response is representative of several student responses that noted the advantage
558 of reviewing and revisiting virtual field trips and field sites after an initial experience. This
559 includes several students that attended on-location field trips, who indicated a curiosity
560 about, and an awareness of, the potential for virtual field experiences. Some examples
561 of these responses include:
562   *"I took all in-person geology courses prior to graduating, so I was never given the*
563   *option to take any field trips virtually, but I wish I could have seen how they may*
564   *have worked, and what software was used."*
565
566   *"The virtual field trips in google earth are very well done and I think those things*
567   *are helpful."*
568
569   *"...I have never attended an online field trip, so I am unfamiliar with them. It would*
570   *be nice to have the opportunity to catch anything I might have missed during field*
571   *trips [due to] loud cars, not [standing] close enough to the speaker, or having to*
572   *sit out on a few steep outcrops."*
573 The response above also highlights the inclusivity of virtual field experiences, where
574 every student has an equal opportunity to examine and investigate each outcrop and
575 participate with other students and instructors, regardless of physical ability or proximity
576 to ongoing discussions. Accessibility aspects of virtual field experiences are discussed
577 in more detail in the section that follows.
578
579 *4.2 Student Views on Disabilities and Field Access*
580 Survey results indicate that a majority of SST students agreed that students with
581 disabilities may be deterred from majoring in the geosciences due to the expectation
582 that fieldwork is a necessary component of upper-level courses (Figure 7.) Many SST
583 students, across both learning modalities (in-person and virtual,) indicated an
584 awareness of challenges and issues associated with disability access in field settings.
585 As one student noted,
586   *"...the geosciences in general have a stereotype of being the science of the*
587   *rugged outdoorsman, and that deters people with disabilities."*

589 Figure 7. Responses from students of both in person and virtual modalities on
590 whether they thought students are discouraged from majoring in the geosciences
591 due to a fieldwork requirement in undergraduate curricula.
592

593 Table 1 contains narrative responses from the student survey that reflect disability
594 access and inclusion issues for field trips, including those in the SST course. Several
595 SST students dealt with accessibility challenges during the on-location field trips and
596 indicated that they would have welcomed the option of viewing and investigating
597 outcrops virtually. Students that participated in virtual field trips also indicated an
598 awareness of field access issues for students with disabilities, as highlighted in the last
599 few responses in Table 1. Regardless of whether students had experience with virtual
600 field trips, there was recognition that issues like navigating topographic relief to see
601 outcrops close-up, or just getting in and out of vans multiple times during a trip,
602 presented challenges for some students. Virtual field experiences were seen as a viable
603 alternative by many students, regardless of whether they had experience with virtual
604 modalities.

Student Comments on Disability Access and Inclusion in the Field
Comments from students that took SST in person
"Physical challenges such as knee/joint/etc. pain as well as heart issues, affected my ability to fully interact with the outcrops (especially ones that required foot travel)."
"I had a knee injury that prevented me from standing for long periods of time, climbing up or down to see certain outcrops, and needing help when taking measurements like strike and dip because my balance was not exactly up to par. I did not get to see every outcrop or help take measurements, and I felt that I was more of a burden to my group then a help overall because of this."
"Many field trips … involved climbing very steep inclines which worried me with some of my health issues. If you didn't climb, you missed out."
Comments from students that took SST virtually
"…the virtual field trips offer an opportunity for students with physical limitations to participate … it is a good option for them, but the other students need the in person experience out in the field as well."
"…if it were not for covid, I would not have been able to really participate in field trips."
"I can definitely see how disabilities could make physical field work difficult, but the online presentation of the material is very useful and efficient…"
"The google earth features with field trip info at each stop … is certainly … accessible and helpful to those with disabilities in most cases."

Table 1. Responses from the student survey that discuss disability access and inclusion issues for field trips. Responses are grouped according to modality of learning environment (in-person or virtual.)

Student responses also highlighted the potential for technological solutions to augment field experiences. Some students were made aware of the potential for mobile communications devices to augment field experiences for disabled students via a student presentation that highlighted ongoing research (Atchison et al., 2019; Whitmeyer et al., 2020.) The responses below were from students that attended SST in-person, but recognized the potential of technology for improving field access:

"I saw the use of ipads and video chats to help those with physical disabilities that may not be able to visit certain onsite locations."

619   *""…the student had tested a novel system for broadcasting outcrops which were*
620   *inaccessible to students with disabilities through livestreaming on an ipad or*
621   *similar technology. Seemed like it had a lot of potential!"*
622 These responses highlight the possibilities for enhancing accessibility in the field and
623 suggest ways for improving inclusivity for SST and other geoscience courses, as a
624 hybrid approach to virtual and in-person learning.
625
626 *4.3 Student Perception of Academic Growth during the SST Course*
627 Students were asked to self evaluate their academic growth from the beginning to the
628 end of the course. The survey instrument used a scale of 1 (little academic growth) to
629 10 (most academic growth possible) to facilitate evaluation of overall academic growth
630 during the semester, as well as growth in key topics in the general areas of stratigraphy,
631 structure, and tectonics (Table 2.)
632

Academic Growth in Key Topics of Stratigraphy, Structure, Tectonics (SST) Course					
	Students that Took the Course In-Person		Students that Took the Course Virtually		Discrepancy in
Topic	Mean of Responses	Range of Responses	Mean of Responses	Range of Responses	Means of Responses
a. Identifying and understanding depositional environments	6.90	3 - 10	6.18	2 - 10	0.72
b. Constructing strip logs	6.90	3 - 10	5.27	1 - 9	1.63
c. Ability to apply the geologic time scale on field trips	7.43	4 - 10	6.82	3 - 9	0.61
identification of geologic structures	8.05	5 - 10	6.73	3 - 9	1.32
e. Evaluating structural concepts and deformation	7.14	2 - 10	7.09	4 - 10	0.05
f. Tectonic Interpretations of Rocks and Minerals	6.43	3 - 9	6.09	4 - 9	0.34
g. Interpreting and applying the Wilson Cycle	6.95	3 - 10	5.73	2 - 10	1.22
h. Understanding tectonic events through time	7.29	3 - 10	7.00	4 - 9	0.29
Overall academic growth	7.57	5 - 10	6.64	3 - 8	0.93

633
634 Table 2. Student survey responses highlighting self-evaluation of academic growth from the
635 beginning to the end of the Stratigraphy, Structure, Tectonics (SST) course. Responses are
636 grouped by whether the students took the course in-person (*n=21*) or virtually (*n=11*.) Key topics
637 highlighted include those with a stratigraphic focus (a,b,c), those with a structural focus (d,e),
638 and those with a tectonics focus (f,g,h). Academic growth is reported on a scale of 1 - 10, where
639 1 = little academic growth and 10 = the most academic growth possible; means of responses
640 and ranges of responses are indicated.
641
642 In all categories students that took the course in person reported higher mean scores
643 than students that took the course virtually. In general, stratigraphy topics displayed a
644 greater discrepancy in mean responses between students that attended in person and
645 students that attended virtually. However, the topical categories that show the greatest
646 discrepancies between in person and virtual attendance encompass all three general
647 areas: strip logs (deviation of 1.63; stratigraphy), cross sections (deviation of 1.32;

648 structure), and the Wilson Cycle (deviation of 1.22; tectonics.) It is worth considering
649 that these three categories represent topics that require synthesis of data in the
650 preparation of summary diagrams, interpretations, or models. This disparity between
651 modes of attendance in students' perceptions of their abilities to synthesize data may
652 also be reflected in the relatively significant discrepancy (0.93) in their evaluations of
653 their overall academic growth during the semester.
654 Student perceptions of their academic growth during the SST course reflected
655 classroom, laboratory, and field learning environments. Thus, the deviations between
656 the higher self-reporting scores for students with in-person attendance and the lower
657 scores for virtual attendance do not only reflect on-location vs. virtual field experiences.
658 However, several topics that directly address field-oriented learning (constructing strip
659 logs, ability to apply the geologic time scale on field trips, interpreting cross sections and
660 identification of geologic structures, understanding tectonic events through time)
661 indicate that students that participated in virtual field experiences were generally less
662 confident of their academic growth in field-focused learning than students that
663 participated in on-location field trips. Several factors likely contributed to this result.
664 First, the SST instructors have many years of experience with on-location field
665 trips and have fine-tuned the MAAOT trips over the course of several years to maximize
666 the student experience. In contrast, Fall 2020 was the first semester in which the field
667 experiences were fully virtual, and it is likely that the student learning environment was
668 less effective and less positive as a result. Many SST students seem to look forward to
669 the field trips as highlights of the course, and in 2020 many students expressed
670 disappointment or even apprehension (e.g. Figure 6) that the field trips would have to
671 switch to virtual delivery and participation. These apprehensions are highlighted in some
672 qualitative responses to the student survey; for example:
673 *"As someone who would not consider themselves to have a severe disability,*
674 *[the SST course] still took a huge toll on me both physically and mentally."*
675
676 *"We are told that a geologist is only as good a geologist as the amount of*
677 *geology they see and a lot of people with disabilities can't see all of the things*
678 *able-bodied people can."*
679
680 Reduced enthusiasm for the virtual field component of the course may have resulted in
681 less effort by the students. However, apprehension for on-location field trips on the part
682 of students with mobility challenges or other environmental concerns may have been
683 alleviated once students gained experience with virtual field trips. In addition, it is likely
684 that the general frustrations of both faculty and students with the restrictions imposed by
685 the COVID pandemic had negative effects on the academic learning environment as
686 well as on general living conditions. These effects are hard to quantify but were certainly

687   experienced by the authors and expressed to them by many students during the Fall
688   2020 and subsequent semesters that were impacted by the pandemic.
689
690   **5. Discussion**
691   Many of the challenges faced by instructors with the switch to virtual field experiences
692   revolved around determining the most effective ways to accomplish traditional field
693   learning goals (e.g. Mogk and Goodwin, 2012; Petcovic et al., 2014) within a less
694   familiar virtual environment. Engaging students in a dialogue can be challenging in a
695   virtual environment where students may or may not have web-linked video cameras
696   turned on, and may have other distractions going on concurrently in their home
697   environments. Asking students to focus on virtual images of outcrops to discern salient
698   features is not the same as tactile investigations of an outcrop in the field. Important
699   outcrop details usually need to be highlighted in an image through annotations (e.g.
700   Figures 3c, 4b) or explained in a video. This is not the same experience as directing
701   students to examine an outcrop to find these features for themselves. However, if an
702   effective dialogue can be established between students and instructors in the virtual
703   environment, many of the same interpretation and synthesis goals can be achieved
704   through probing questions and repeated directed observations. One advantage of virtual
705   field trips is that supporting diagrams, models, and other materials are immediately at
706   hand and can be easily displayed (e.g. Figure 3d) and annotated in real time by
707   instructors and students. Similarly, process-based models that sequentially change
708   through time can be easily displayed virtually, which would be more challenging to show
709   and discuss on location in the field. These and other relative advantages and
710   disadvantages of virtual field experiences vs. on-location field trips are discussed in
711   more detail below.
712
713   *5.1 Pedagogical Advantages and Disadvantages of Virtual vs. On-Location Field*
714   *Experiences*
715   On-location field experiences have been the traditional format for field-based education
716   for many years, and virtual field experiences are typically evaluated in comparison to
717   on-location trips. If the statement attributed to Herbert Harold Read that "The best
718   geologist is the one that has seen the most rocks." (Young, 2003, p. 50) has merit, then
719   virtual field experiences would seem to have inherent weaknesses that could be
720   challenging to overcome, some of which are readily apparent, such as:
721   1. The tactile components of on-the-outcrop investigations. On virtual field trips
722   students do not experience their own self-directed examinations of the rocks
723   (minerals, fabrics, structures,) which can inhibit observationally-grounded
724   geologic interpretations. Field skills, such as using a hand lens for detailed
725   observations or taking outcrop measurements with a geologic compass, are not
726   effective in a virtual environment, and thus students don't have the opportunity to

727   practice and refine these field-oriented skills. In addition, recollection of the
728   geologic features of an outcrop can also be enhanced by tactile experiences.

2. A clear appreciation of the spatial dimensions of the region and the relative
   locations of outcrops. Virtual experiences via Google Earth are effective in
   showing birds-eye or regional views of a field trip area, but the actual separation
   and distance between each outcrop is more easily grasped when physically
   traveling from location to location on the ground, whether walking or driving.

3. Learning safety in the field. During on-location field trips instructors spend
   significant time and effort highlighting outcrop safety. MAAOT field trips
   incorporate many outcrops that are roadcuts along busy highways, and many of
   these outcrops are steep or subvertical and tower above the students.
   Throughout an on-location field trip, participants are encouraged to wear
   reflective vests, and instructors are constantly yelling "Rock!" or "Car!" to
   encourage safety on the outcrop; this sense of awareness of one's surroundings
   and physical environment cannot be experienced virtually.

4. A sense of appreciation and enthusiasm for the natural world. Historically, one of
   the drivers for recruitment in the geological sciences is the sense of wonder and
   excitement that students obtain from being physically present in awe-inspiring
   natural settings (e.g. Carson, 1965; Petcovic et al., 2014.) This emotional
   connection with the real world is not present in virtual electronic environments.

However, virtual field trips offer some distinct advantages, as highlighted below with
reference to the MAAOT field trips.

1. On virtual field trips it is not necessary to visit outcrops in the order dictated by
   geography and the local road network. In the region of the MAAOT it is possible
   to visit many formations in stratigraphic order, but that is not always the case in
   other regions. In areas where outcrops are not chronologically sequenced, field
   locations can be mixed and matched, using Google Earth to keep students
   geographically oriented.

2. On an on-location field trip each outcrop has to be examined for every piece of
   stratigraphic, structural, and tectonic evidence while at the outcrop. This tends to
   make field notes complex and chronologically disjointed, and can break up the
   rhythm of interpretations. On a virtual field trip a series of outcrops can be visited
   to understand the structural details, then revisited to focus on stratigraphic
   details, and then revisited again for basin analysis and tectonics. It can take more
   time, but this approach can facilitate better organization of the information by
   students.

3. An on-location field trip cannot easily incorporate observations from related but
   distant outcrops of the same formation that illustrate variability or regional facies
   changes. On a virtual trip, stops at different locations that feature the same rock

767   unit can be visited sequentially as a group to cohesively present the data
768   available, and investigate changes across distances.

769 4. Because the MAAOT virtual field trips incorporate PowerPoint supplemental files
770   it is possible to include many images that might not be easy to examine on
771   location at an outcrop. For example, environmental interpretations of the Juniata
772   and Tuscarora Formations (Field trips 3 and 4) can be facilitated and enhanced
773   by using pictures of contemporary tidal flats and beach/barrier island systems.
774   Or, for the Acadian Catskill clastic wedge, atmospheric circulation models and
775   paleo positions, as well as paleontological evidence, can be helpful for
776   reconstructing possible environmental conditions during deposition.

777 5. In virtual field trips, all of the students get the same amount of time and
778   opportunities to examine an outcrop. In contrast, with large classes and small
779   outcrops, in on-location field trips instructors cannot be sure that everyone has
780   had ample time on the outcrop to see all of the salient details. Similarly, students
781   may not have had equal opportunities to discuss the outcrop with the instructors.
782   In addition, some outcrops are physically challenging to get to (e.g. the necessity
783   of climbing steep or unstable slopes to see an outcrop.) With virtual field trips all
784   students have equal access to an outcrop.

785 6. Students can easily revisit virtual field trips and field locations for quick reminders
786   and reviews, as long as the virtual field trip files are made available during and
787   after the instructor-led field trips. This can be an effective mechanism for student
788   teams to revisit MAAOT field trip sites while they are working on their cross
789   section interpretations and synthesis reports.

790 7. The GE virtual format provides the opportunity to take field trips to distant
791   locations that might not otherwise be feasible or practical for on-location field
792   trips. As the library of high quality virtual field trips accumulates (e.g. NAGBT's
793   Teaching With Online Field Experiences site) it will be possible to take students
794   on field trips to many places in the world that otherwise might not be accessible.

795

796 *5.2 Student Perceptions of Hybrid Field Experiences*
797 Survey results indicate that students that took SST in-person generally were unaware of
798 virtual field experiences. For students steeped in the tradition of observing and
799 interpreting geology in the field, it is not surprising that they did not envision options for
800 virtual or remote field experiences. However, while several student responses from the
801 survey highlighted the perceived importance of on-location field trips, other comments
802 recognized the potential for a hybrid approach that incorporated both on-location and
803 virtual features. Survey responses from students that noted specific benefits to a
804 combined hybrid approach are highlighted below.

805   1. Field accessibility
806   *"Offering more virtual options to students in the future, even if most of the class*

chooses to do in-person versions. I think most students, like myself, prefer in-person field trips, but I can see how it may be hard for some students to do that."

"For outcrops that I was (and other individuals were) unable to traverse to/focus on, incorporating a 'virtual' aspect, similar to what's being offered now, would've been useful to allow us to see the outcrop without having to forgo the experience/knowledge."

2. Revisiting field sites:
"…a virtual option for outcrops, … where I would be able to catch up on the material I was unable to [see], would be vastly useful."

"Having a resource of a digital version of the [field] trip, with some key photos and points of the stop to assist in aligning personal notes with the stops would have been a helpful re-enforcer."

3. Incorporating modern mobile technologies to enhance inclusivity
"Virtual field trips in addition to physical/in-person ones – i.e., having someone with a cellular-enabled iPad come along on the field trips to stream video back to anyone who didn't/couldn't join."

4. Using virtual field experiences in combination with on-location field trips
"Using Google Earth to conduct virtual field trips was difficult and not the same as an in-person field trip but combining the use of Google Earth with in-person trips may be beneficial."

"I think some of the resources we used in online learning were extremely helpful, such as the Google Earth stops and the images of the outcrops in better conditions. I don't think they substitute for the in-person experience, but if field trips might become a mix of in-person observation and data collection plus recorded/online chalk talks, it might be beneficial."

5.3 Future Impacts of Virtual Field Experiences

With the Fall 2021 transition back to an environment where on-location field trips are once again possible, SST instructors are using the MAAOT virtual field experiences to augment the five on-location field trips. In general, students were eager to return to the tactile, on-the-outcrop experience of on-location field trips. However, they also appreciated the added perspectives of the virtual field experiences to enhance the learning and review process. For the SST instructors, experiences and insights derived from running MAAOT field trips virtually in Fall 2020 impacted how on-location field trips

847 were conducted in Fall 2021. Instructors noted two key components of virtual trips that
848 could enhance on-location field experiences, specifically: 1. the ability to incorporate
849 outcrop examples from locations that could not be visited in person, and 2. the ability to
850 conduct synthesis discussions that incorporated outcrop data and interpretations from
851 multiple locations. For the Fall 2021 on-location field trips the instructors prepared
852 posters that synthesized data and theoretical models from the VFE Powerpoint "chalk
853 talks" and displayed these on the sides of vans to augment in-depth discussions at key
854 outcrops. These posters also helped with bundling outcrop observations and
855 interpretations across several field sites in order to discuss and interpret geologic
856 features that evolved across a regional scale. The instructors envision that other
857 aspects of the VFEs will be incorporated into future on-location field trips. Ultimately, the
858 authors view a hybrid field experience that incorporates feature of both virtual and on-
859 location field trips as a more inclusive approach to field-based learning and a richer
860 pedagogical experience for all students.
861
862 **6. Conclusions**
863 Virtual learning, whether in the classroom, lab, or in the field, may not be an appealing
864 or effective solution for all students. Interestingly, students that attended SST in-person
865 were more supportive of virtual learning options, perhaps reflecting a desire that these
866 options had been available when they took the course. A key consideration is that some
867 traditional on-location field experiences can be challenging for students with physical
868 and other disabilities, and geoscience departments need to have alternatives in order to
869 accommodate all current and prospective students. For future students that may be
870 unable to visit certain outcrops, a virtual field experience will provide them with a way to
871 investigate an outcrop and participate with other students in a meaningful and
872 knowledgeable way. This is not only an ethical consideration, but also important from a
873 recruitment perspective, where geoscience educators need to welcome students from
874 all backgrounds in order to ensure the continued health of the discipline.
875   Another consideration is the continuing uncertainty of the COVID pandemic
876 situation and the possible impacts of future variants. Throughout the Fall 2021 semester
877 we unfortunately are witnessing repetitive surges of COVID cases, underscoring the
878 potential for restrictions to travel and field access at some point in the future. With the
879 development of virtual field experiences, such as those included in the MAAOT project,
880 instructors have alternative options if on-location access to field sites is restricted. The
881 necessity for virtual field options has always existed for some geoscience students, but
882 the COVID pandemic has made all of us realize that these virtual options need to be
883 available to the full community of students and instructors.
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887 **Author Contributions**
888 All authors contributed to the writing of the manuscript. HL drafted and administered the
889 student survey and collected the student data.
890

891 **Competing interests**
892 The authors declare that they have no conflicts of interest.
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894
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