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ORIGINAL ARTICLE

Quantifying Virtual Field Trip Efficiency

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Abstract

The efficiency of virtual field trips (VFTs) compared to their physical counterparts, is often regarded as one of their key benefits. Virtual field trips are typically more time, cost and environmentally efficient and logistically easier to plan and execute. This is largely due to the lack of travel, however, the nature of these efficiencies, which is essential for deciding whether a trip should be virtual, physical or blended, have not previously been quantified. Here we present a quantitative evaluation of several measures of efficiency, using data from a like-for-like comparison between 10 day long virtual and physical field trips to Utah, USA, from the University of Aberdeen, UK. For this case study, our results demonstrate that virtual field trips are more efficient across all the categories of time, cost, environmental impact, and logistics. In addition to saved air travel days at the start and end of the physical trip, a further 33.3% of the time on the physical field trip was spent travelling (walking and driving). This time saving allowed an additional 16 localities to be visited on the virtual field trip. The virtual field trip localities also ran in an order that best suited the geological narrative rather than their geographic location which the physical field trip was restricted by. Flights and driven kilometres for the physical trip produced c. 4 t of carbon dioxide equivalent (CO_2) per student. The virtual trip produce <1% of the CO_2 and was comparable to a typical teaching week, making it significantly more environmentally efficient. The cost of the virtual trip was negligible compared to that of the physical trip (saving up to £ 3000 GBP per student). These findings were compared to the fulfilment of learning outcomes, quantified primarily through questionnaires, the student responses suggest that the PFT and VFT perceptions of learning outcomes were generally comparable. Efficiency is not the only measure of a successful field trip, with other parameters such as social cohesion and embodiment within the outdoor environment that must also be considered when planning a field trip. Therefore, the authors do not advocate or support an abandonment of physical field trips. Rather, this study aims to provide a first attempt to quantify efficiency to inform decision making when planning field training.

Keywords Virtual Field Trip · Time Efficient · Cost Efficient · Logistically Efficient · Carbon Footprint · Learning Outcomes

1 Introduction

For over a century, physical field trips (PFTs) have been a key component of most geoscience degrees. However, the COVID-19 pandemic resulted in the overnight uptake of virtual field trips (VFTs) due to travel restrictions and social distancing measures. The positive and negative aspects of VFTs as a replacement or compliment to PFTs has been discussed previously (e.g. Cliffe 2017; Dolphin et al. 2019; Pugsley et al. 2022; Smith and McNeal 2023) but these discussions are typically qualitative. The enforced adoption of VFTs during the COVID-19 pandemic provided the opportunity for a unique experiment which allowed direct comparison between PFTs and VFTs (Pugsley et al. 2022). One of the key learnings was the qualitative observations that VFTs are more "efficient", promoting the suggestion that VFTs or elements of VFTs should remain in the geoscience education system. To date, there is an absence of studies focusing on the quantification of these efficiencies, especially with respect to the practical aspects of time, logistics, financial cost, and environmental impact. This study aims to address these questions. A more detailed description of these specific fieldtrips and a comparison of the

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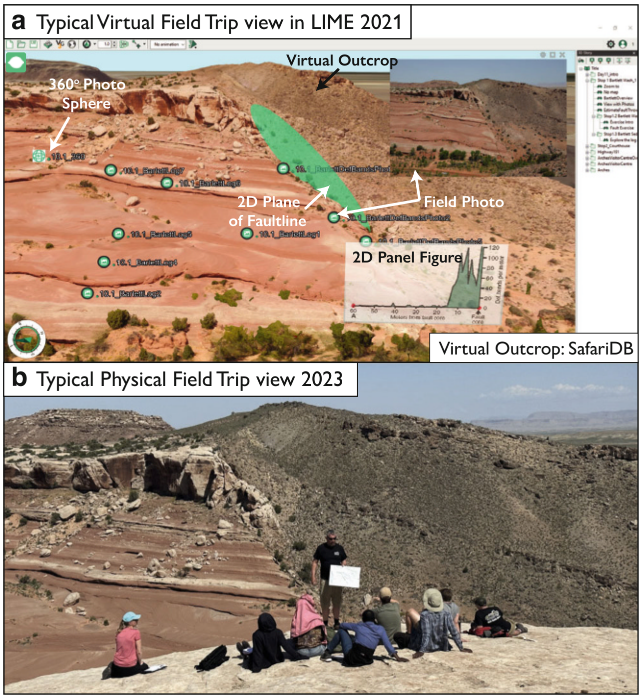

Fig. 1 Typical VFT and PFT views at the same locality of Bartlett Wash, Utah, USA. The task at this locality is to study the fault and its damage zone and consider the impact on subsurface fluid flow. **a** View from 2021 VFT: virtual outcrop imported from SafariDB (collected and processed by VOG Group) and viewed in LIME (Buckley et al. 2019) with additional material including 2D panels (e.g. graphs and logs), photos and 360° photo spheres. **b** View from 2023 PFT of the students being given an illustrated explanation of locality on a whiteboard

student experience between the Utah VFTs and pre-covid PFTs was given by Pugsley et al. (2022).

Previous studies have described some of the advantages of VFTs. They facilitate more participant access to data across a range of scales (Hurst 1998; Arrowsmith et al. 2005; Atchison and Feig 2011; Çaliskan 2011; Bailey et al. 2012). This increased range of data can then be examined by participants as part of the VFT (Senger et al. 2021) such as simultaneously studying virtual outcrops and thin sections. VFTs are more cost-effective (Stainfield et al. 2000; Fletcher et al. 2002; Ramasundaram et al. 2005; Jacobson et al. 2009; Litherland and Stott 2012; Dolphin et al. 2019) and with the removal of physical travel they are also more environmentally efficient than their conventional counterparts (Ramasundaram et al. 2005). VFTs enable geographic independence allowing localities to be visited in order that benefits a narrative rather than for logistical reasons, and VFTs also permit a higher number of individuals to attend (Stainfield et al. 2000; Dolphin et al. 2019), both increasing efficiencies. VFTs run prior to a PFT can be used to introduce the geology, learning objectives and/or logistic information, which can in turn promote efficiency of the PFT itself (Streule and Craig 2016). VFTs may also be pre-recorded or software-led, freeing up staff time beyond the initial building and recording of the VFT, increasing staff efficiency, and allowing greater access to students with part-time work or caring responsibilities.

Addressing learning outcomes and their potential differences within VFTs and PFTs has been a focus of several studies. Through pre- and post-VFT questionnaires Bond et al. (2022) found that all the main learning outcomes could be met over the course of their VFT. Sriarunrasmee et al. (2015) present a learning model to improve learning outcomes within a virtual fieldtrip stating that students were highly satisfied by the learning and produced work of a high level. Klippel et al. (2019) state that their immersive virtual field trip learning experience as well as learning outcomes were on par or exceed those of their PFTs. General learning outcomes may need to differ depending on level, but generally most workers find they can be achieved to a high level over the course of a VFT.

Whilst the advantages of VFTs have been discussed previously, there has been no previous efforts to quantify differences in efficiency (i.e. financial, time, logistic, environmental) and to compare efficiencies between like-for-like fieldtrips. Here we address that point and aims to quantify the efficiency of virtual field trips and compare perceptions of learning outcomes using a near identical field trip to Utah that was run both as a VFT (2021) and as a PFT (2023). To directly compare the Utah VFT and PFT duration analysis was performed for the various activities within the working day across three main themes of (1) active work, (2) breaks and (3) travel. We also calculate the hypothetical distance driven between localities on the VFT to compare to the physical logged kilometres driven during the PFT. In addition, the number of localities examined across both the VFT and PFT, and the financial cost of the PFT per individual were recorded. This quantitative data enables the direct comparison of a VFT and PFT to mostly the same localities, for the same learning objectives at a MSc level. While it may seem obvious that VFTs are more efficient than their physical counterparts, evaluating the elements of efficiency remains a useful exercise. Quantification allows planners (e.g. field trip leaders) and decision makers to make informed choices about when to run a VFT or a PFT and how to focus resources and time. Pugsley et al. (2022) demonstrated that it was possible to replace a PFT with a VFT addressing the same learning outcomes and for the VFT to be positively perceived by students. However, there are numerous tangible advantages to PFTs such as strong group cohesion and individual emersion within the landscape, culture and outdoor environment. Knowing the financial and environmental costs of a PFT versus an equivalent VFT can allow the better allocation of limited resources. It can also lead to efficiency savings in future trips as a way of focusing resources in a hybrid settings where elements of both VFTs and PFTs are used on a course. This paper provides a workflow and example case study which may be used as a template for future discussions on the nature of specific trips.

It is noted that the number of students in the studied MSc class was relatively small (a total of 30, 7 for the PFT 23 for the VFT) and the results here should be treated with a degree of caution due to the limited sample size. However, given the unique circumstances around the COVID-19 pandemic, which are unlikely to be repeated in the near future, we consider the findings to be worth reporting. We also consider the methodology of comparing efficiency between PFTs and VFTs to be useful for future studies.

2 Field Trip Outline

The Utah VFT was created as a direct replacement to the PFT which had been running for over 25 years (Pugsley et al. 2022). Both courses had the same learning outcomes, used broadly the same localities (e.g. Figure 1) and had the same learning objectives and assessments. The VFT ran in 2020 and 2021, while a local PFT alternative was run as a replacement in 2022. The Utah PFT returned in 2023 when the data for this study were collected. The general layout of the VFT and PFT is summarized in Table 1.

2.1 Virtual Field Trip

The VFT was first run in 2020 and was 11 days long. The VFT was rerun over 10 days in 2021with the removal of one day as the first exercise around the Great Salt Lake could be achieved in a single day as the physical travel time between localities was not a limiting factor. Data for this study were collected from the 2021 VFT, which was run on campus in a classroom environment. The VFT was designed to emulate the PFT and was tutor-led in real time through the

Table 1 Description of each day of the VFT 2021 and PFT 2023, day of delivery and number of localities, general locations provided in latitude and longitude

Day Name and Description	Virtual Field Trip		Physical Field Trip	
	Delivery Day	Number of Localities	Delivery Day	Number of Localities
Salt Lake City (40.7608, –111.8910)	1	10	1, 2	9
Large scale exploration play mapping exercise using modern basin and range tectonics around the Great Salt Lake, for an assessed exercise				
Book Cliffs (39.2407, –110.2587)	2, 3, 4	16	3, 4, 5	11
Sequence stratigraphy of the Book Cliffs examining shallow marine sedimentology (shorefaces, river-dominated deltas and tidal estuarine package interpreted as an incised valley complex) and correlation in shoreface parasequences. Finishing with an assessed field development exercise at Thompson Canyon				
San Rafael (38.9201, –110.4318)	5	5	6	3
Cretaceous stratigraphy along the western side of the San Rafael Swell, examining the transgressive deposits of the Dakota/Naturita system and the growth faulted, fluvial-dominated deltas of the Ferron Sandstone				
Distributive Fluvial Systems (38.2924, –111.2604)	6	5	6, 7	5
Fluvial architecture of the incised Shinarump Sandstone at Capitol Reef with the distributive fluvial deposits of the Salt Wash Member of the Morrison. Special reference was made to the recognition of sand-dominated meandering systems				
Igneous (38.4963, –111.2468)	7	5	7	2
The igneous-sedimentary interactions of the Cathedral Valley and Henry Mountain area, and the implications on the petroleum system				
Canyonlands (38.4526, –109.7375)	8	5	9	5
A traverse through Canyonlands, reviewing the stratigraphy and comparing different types of arid continental reservoirs				
Salt Tectonics (38.5719, –109.57)	9	7	8	4
Analysis of the interaction between the salt tectonics related to the Paradox formation evaporites and sedimentation within the Chinle Formation fluvial deposits culminating in a student exercise dealing with exploration in salt basins				
Extension Tectonics (38.7404, –109.5085)	10	7	10	5
Examining extensional tectonics around Moab and within Arches National Park. The students visited a series of localities along the Moab and at the Delicate Arch Relay Ramp				
–	VFT total	60	PFT total	44

online teaching platform Blackboard Learn, GoogleEarth and the LIME software (Buckley et al. 2019, 2022b).

In 2020 there were 30 students and in 2021 there were 23 students. The staffing included three professors, one research fellow and two PhD student demonstrators in 2020. In 2021 the staff numbers were reduced to three professors and one research fellow. The Utah 2020 VFT was the first VFT planned and constructed on this scale by the staff group, it took one research fellow one month of full-time work, and two months of part-time work by the three professors to build. A later week-long VFT to the Pyrenees took a total a month for one post doc and one professors part-time work to build. The time and resource savings were a result of the experience gain building the Utah VFT. The Utah 2020 VFT was reused in 2021, with minor adaptations. Staff had prior experience of using virtual outcrops and LIME (Buckley et al. 2019), with access to both the public (v3Geo, Buckley et al. 2022a) and proprietary (SafariDB) datasets of over 800 virtual outcrops. LIME has a direct import function from both v3Geo and SafariDB, which meant that large virtual outcrops could be easily and efficiently accessed remotely without the need to download and copy large datasets. The software stores the other data for the VFT (logs, photos, maps, diagrams etc) locally and these were distributed to students as zipped folders. These zipped folders ranged in size from 0.1–0.9 GB and were provided to students ahead of time to enable download. To access the outcrops effectively, internet speeds of >6 Mbps were required, however, all students had far higher speeds on the 2021 VFT as it was run in the University. This meant students were able to open and interact with large virtual outcrops on standard and even lower quality home computers and without the need for high performance desktops. The 2021 Utah VFT included 30 virtual outcrops (Buckley et al. 2008), 23 DEMs, 313 photos, and 112 logs/wells (Pugsley et al. 2022), with all data collected prior to the COVID-19 pandemic or sourced online (e.g. 360° photos from google street view). The VFT enabled one additional day examining igneous-sedimentary interactions, which was only briefly visited on the PFT at the end of the Distributive Fluvial Systems day due to its relatively close geographic location. The average VFT day length was 7 h and 19 min, with structured breaks throughout the day to enable students time away from their screens.

Over the course of the trip 60 localities were visited virtually (Fig. 2). The hypothetical driving distance between the localities in order of delivery was 3998.2 km. Commute time for individual students and staff to and from the university was not recorded, all participants lived within or around the city and all but two walked to the University. Once built the Utah VFT was run twice for the students and the same material, with some adaptations, has been used multiple times for various audiences from conference workshops to industry VFTs. Further information on the VFT construction, delivery and perceptions are detailed in Pugsley et al. (2022).

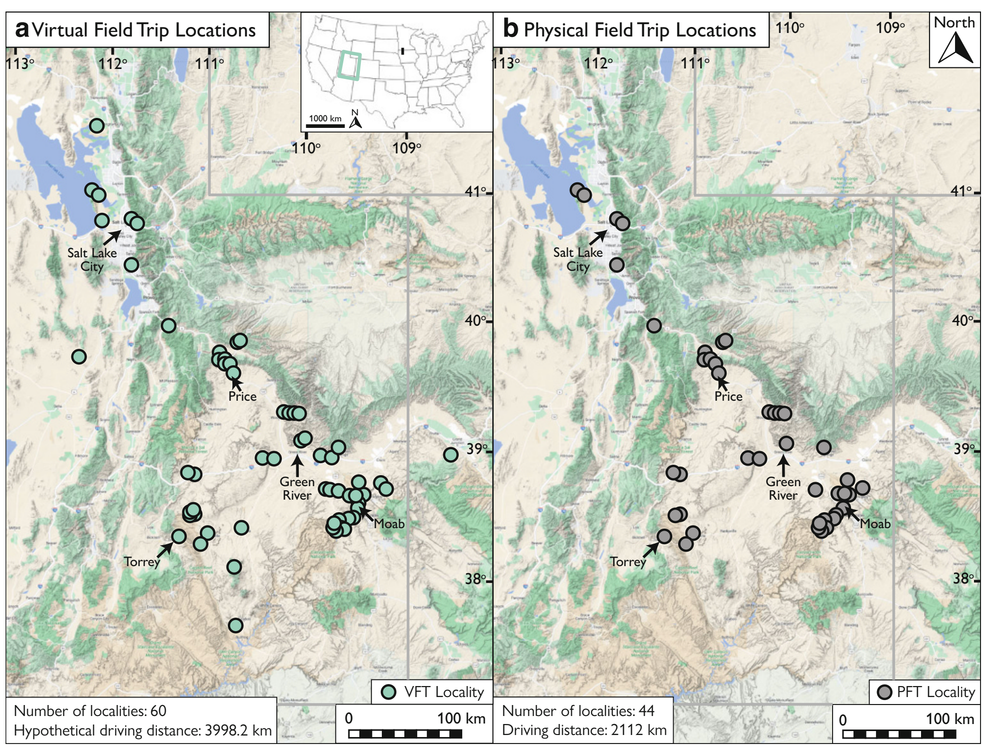

Fig. 2 Map illustrating localities visited across the Utah field trips. **a** The virtual field trip map of localities visited which totalled 60 hypothetical driving distance between localities in the order presented would have resulted in 3998.2 km of driving. **b** The physical field trip map of localities visited which totalled 44 driving distance over the course of the field trip totalled 2112 km. The virtual field trip localities are more numerous and present a wider geographic spread. Foundation map from Google Maps, Default and Terrain, Map data November 2023

2.2 Physical Field Trip

The 2023 Utah field trip was the first PFT after the COVID-19 pandemic and followed the same outline of the pre-pandemic PFTs with some minor changes, including the integration of the Google Earth Pro kmz within to the first exploration play mapping exercise around the Great Salt Lake. The field trip included 10 days in the field, 1 day off, and 2.5 travel days (flying Aberdeen to Utah return) totalling 2 weeks away. An unusually low number of students (7) formed this cohort. The staffing included two professors and one research fellow. This is also an unusually high staff to student ratio, albeit necessary for knowledge, safety, and research (including the data collection of this study). For reference, the same number of staff have taken 30 students in previous pre-pandemic years PFTs. The average day length from leaving a hotel in the morning to arriving to a hotel in the evening was 9 h and 49 min. Over the course of the field trip, 44 localities were visited, and the total driving distance per car, of which there were 3, was 2112 km (see Fig. 2).

3 Methodology for Quantifying Efficiency

3.1 Quantifying Duration Analysis

Activity categories were discussed and subdivided prior to the 2021 VFT and tested on the earlier rendition of the Utah VFT in 2020 to ensure they included all activities over the duration of a field trip. Activity categories were separated into (1) active work, where students were taking part in the coursework and material, further subdivided into, tutor explanation, independent work, group work, discussion and student presentations; (2) breaks, allocated time off and (3) travel, walking or driving between localities (not applicable for VFT). These are further described in Table 2. Over the course of both field trips, an iPhone 'Clock' app was used on the stopwatch function, started at the beginning of each day, with each activity start/end recorded as a lap to ensure all time was accounted for by an activity. The recorded times were listed onto a spreadsheet, then collated at the end of each day.

3.2 Quantifying Logistics

During the physical field trip, the kilometres travelled over the course of each field day, starting at the accommodation, between the localities then returning to the accommodation were recorded using the Google Maps app. For the virtual kilometres hypothetically travelled, each locality was pinned in order delivered within the Google Maps app. The hypothetical routes were recorded from the equivalent accommodation used on the PFT, then the localities in the order of delivery, and return to the equivalent accommodation.

3.3 Quantifying Cost

The cost was calculated as the total cost of the physical field trip for each student including flights, accommodation, and car hire. Food (excluding breakfast included in accommodation price) was not included as part of the overall price. The price of the physical trip is included within tuition fees. Tuition fees were retrospectively corrected during the pandemic to account for the lack of the physical field trip.

3.4 Quantifying Environmental Impact

To quantify the travel related environmental impact of the PFT the total tonnes of carbon dioxide equivalent (CO_2) emissions per person and collectively was calculated for the flights and cars. For consistency and the ability to compare the result we chose to use the Target Neutral carbon emissions calculator (https://www.bp.com/en_gb/target-neutral/home/calculate-and-offset-travel-emissions.html#/: Last accessed December 2023), we would like to note that there are other calculators available potentially producing similar but not identical results. The return flights were Aberdeen to Heathrow, Heathrow to Denver and Denver to Salt Lake City, then three vehicles were hired for the trip, including two large cars and a medium car were imputed into the calculator.

The first VFT (2020) was run at the height of the pandemic when all students and staff were at home so there were no travel related CO_2 emissions. For the 2021 VFT the course was run on the University of Aberdeen campus. The majority of students (all except two) live on or within walking distance of the campus. The staff live slightly further away, and it is recognised that their commutes produced some CO_2 emissions. To calculate CO_2 for the three staff and driving students we again used the Target Neutral carbon emissions calculator. Students taking public transport or taking any other form transport (e.g. e-bike or e-scooter) which may produce a CO_2 emission, though notably small, were not calculated. Generally the typical carbon dioxide equivalent (CO_2) for a single desktop and screen used for eight hours is 70 g as quoted by the University of Oxford (https://www.it.ox.ac.uk/article/environment-and-it: Last Accessed July 2024), this metric was used to calculate for the 10 days for 23 students and 2 members of staff. Estimates for the CO_2 of the cloud storage sites for the virtual outcrops were not available but are considered negligible, since the cumulative time spent serving a model is seconds per day.

Table 2 Activity category descriptors for the Utah VFT and PFT

Activity Category	Virtual Field Trip	Physical Field Trip
Active Work		
Explanation of talk/ assessment	Outlining aims and objectives at start of day, for an assessment or at a locality	Outlining aims and objectives at start of day, for an assessment or at a locality
Independent work	Students working independently, exploring the virtual outcrop and supplementary data in LIME on their own or in small undefined groups	Students working independently, exploring outcrop on their own or in small undefined groups
Groupwork	Students working as part of team, as requested by staff, such as one individual sharing screen or in larger assessment groups	Students working as part of team, as requested by staff, such as in pairs for logging exercises or larger assessment groups
Geological explanation and discussion	Staff explaining a locality, often by sharing their screens to show LIME. Within the VFT there was more structure, and it was easier to separate opportunities for discussion as students were presented to, with questions then posed to initiate discussion at each locality and time allocated at the end for student questions. However, discussion and geological explanation are grouped for comparison with the physical field trip	Staff explaining an outcrop, often with whiteboard illustration once students have explored the locality. Given informal nature of the geological explanation (e.g. staff member standing at front of group) it typically led into questions and discussion on individual points, the whole locality, wider regional context, or implications for application. Therefore, the difference between geological explanation and discussion was less clear
Student Presenting	Students presenting by sharing screen, often one individual screen, with group members sharing their microphones. Typically, at start or end of day, if needed/possible virtual field days were shortened to accommodate time for presentations and groupwork	Students presenting PowerPoint slides to staff and/or other students in a formal setting with a projector. Typically, at start or end of day, if needed/possible field days were shortened to accommodate time for presentations and groupwork
Breaks		
Blank Time	Time waiting such as for students to re-join the virtual classroom after agreed start time	Time waiting such as unloading car, packing car, or time running late from agreed start time
Lunch	Time allocated to eat in the middle of the day, typically pre-agreed to be 1 h	Time allocated to eat in the middle of the day, typically before or after a locality with students either eating in car or on public picknick benches
Break	Time allocated for breaks such as coffee/tea and toilet	Time allocated for breaks such as shopping for lunch and specified toilet stops
Travel		
Travel	No travel recorded, students working from home or a locality of their choice travelling outside of teaching time	Walking or driving between localities, flight times to Utah not included and allocated as an additional day either side of field trip

3.5 Quantifying Fulfilment of Learning Outcomes

Evaluating the fulfilment of learning outcomes during VFTs is fundamental when considering efficiency. The completion of learning outcomes was evaluated through questionnaires by asking specific questions on each of the learning outcome. Ethics approval was granted for questionnaires by the University of Aberdeen. Following the university guidelines, questionnaire participation was voluntary and anonymized. Participants were requested to respond to a sequence of questions rating their experience between 1 (disagree) to 5 (agree) and were able to give qualitative statements within an open text box. The same format was used for both questionnaires with equivalent questions for VFT and PFT. The completion rate for the Utah 2021 VFT was 91% (21 out of 23) and for the Utah 2023 PFT it was 100% (7 out of 7). For the VFT students were encouraged to complete the questionnaire at the end of the VFT in the classroom, with a deadline of 2 weeks after the end of field trip for responces. For the PFT the questionnaire was sent to the students at the end of the trip, again with a deadline of 2 weeks to complete. While a dataset of only 26 students is a small study group and may weaken some of the conclusions, this was outside of our control, we had to work with the available data but still find the result to be worth reporting given this is the first study on quantification of efficiency. Future studies of larger groups following this methodology would help to test and validate these initial results.

The use of questionnaires is routine within the academic curriculum to gauge participant perception. However, there must be an acknowledgement of the potential issues of self-reporting (Spooren et al. 2013; Boring and Ottoboni 2016; Esarey and Valdes 2020). The notion of understanding is not a true gauge of understanding, and participants cannot know the exact level of their understanding (Kuorikoski and Ylikoski 2015). Also, participants can only reflect on their own experience and as a result are unable to truly compare between a PFT and VFT if they have not attended both. While it is not possible to truly standardise this form of questionnaire data, it is still a useful measurement for general participant opinion.

4 Results

4.1 Duration Analysis

While the VFT was a direct replacement of the PFT, the virtual set up provided the opportunity to incorporate additional localities that were otherwise located too distantly to be included in the PFT. Conversely, there were a handful of localities which virtual outcrops had not been collected from and no other suitable virtual data were found and therefore the locality was excluded from the VFT. The VFT and PFT daily average for each activity themes are outlined in Table 2. For the VFT 70.2% of the student's working day was spent conducting active work, whereas for the PFT it was lower at 50.1% (see Fig. 3). Breaks took up 29.8% of the working day for the VFT, whereas the PFT was lower at 16.6%. With the VFT breaks were specifically allocated to give participants time away from their screens and physically move in line with good health and safety practice, therefore this higher percentage was expected. Travel time did not contribute towards the VFT as all students lived in Aberdeen or nearby and therefore commuted onto campus, typically less than 20 min. In 2020, commute times were even less with most students working from home in line with COVID restrictions. For the PFT, exactly a third (33.3%) of the trip was spent either walking or driving between localities.

Activities were divided into more detailed categories within the three themes of active work, breaks and travel (see Fig. 4), Table 2 lists category descriptions. The biggest contrast between the duration analysis for the field trips was travel, which included driving and walking between localities on field days. On average, a third of each day was spent travelling which equalled 3 h and 16 min. A further day either side of the fieldtrip was required for flight travel, which further increases the time expended by travel, though not included in the daily average.

Within active work, geological explanation and discussion consumed the most average daily time, with almost 2 h and 45 min spent during the VFT and a slightly lower at 2 h and 24 min for the PFT. However, it is noted that informal discussions continued during travel time of the PFT. For explanation of task/assessment the VFT daily average time was 3 min and 40 s, whereas for the PFT it was close to 11 min, likely longer owing to more time spent explaining logistics (e.g. safety and walking routes). Student presenting time was a little over 14 min for the VFT and 8 min for the PFT, the difference due to the larger student numbers on the VFT resulting in more groups presenting and a higher

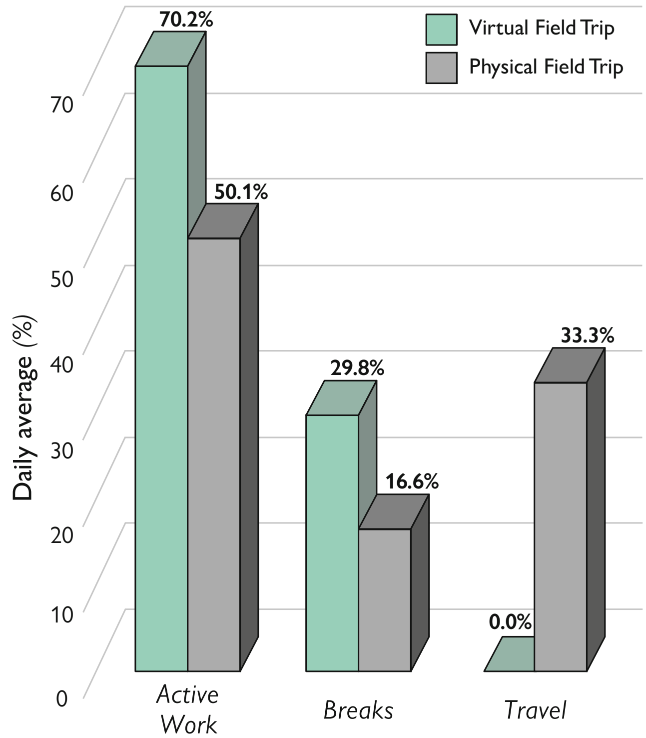

Fig. 3 Daily average of the three main themes of active work, breaks and travel or the VFT and PFT

collective average time. For Independent work, the VFT had an average daily time of 34 min, whereas the PFT had a considerably longer 1 h and 20 min. For groupwork, the opposite occurred, the VFT has a much longer daily average of 1 h 39 min, whereas the PFT had a much lower time at only 52 min. These differences are not a direct result in varying activities between the VFT and PFT, instead they are likely a result of students during the VFT often being told to 'explore in groups' as opposed to 'explore'. The use of the suggested use of groups was often used to promote discussion, whereas at PFT locations students naturally and informally started discussions.

Within the theme of breaks, lunch showed the biggest difference between the VFT and PFT, with the VFT (1 h 6 min) lunch consumed double the time of the PFT (32 min). As the VFT was run in real time, designated hour-long lunches aimed to help break up the day, whereas on the PFT lunch was simply for eating as travel broke up the day and enabled people to rest. Designated breaks were nearly the same at 43 (VFT) and 42 (PFT) minutes. Blank time was longer during the PFT (25 min) than the VFT (15 min).

4.2 Logistics

As VFTs can be geographically independent, they enable the field trip to run in an order of the best geological narrative rather than the geographic location and are also weather

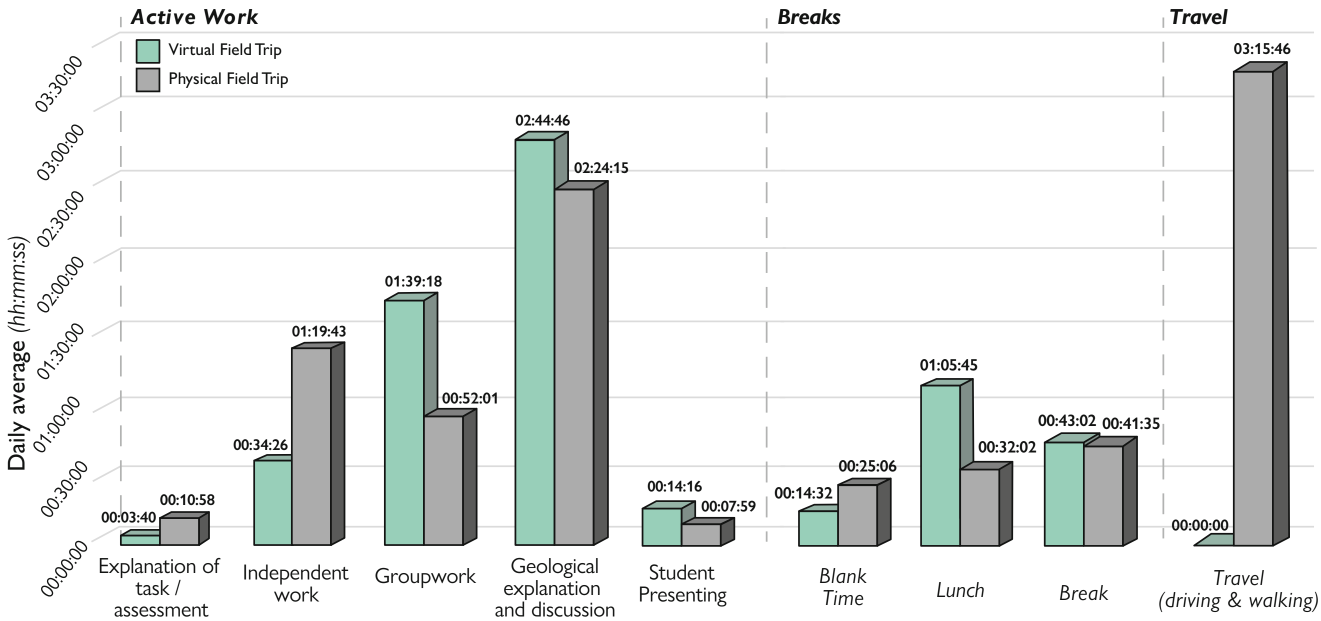

Fig. 4 Detailed duration analysis across overall field trip including active work, breaks and travel activities

and tide independent (Dolphin et al. 2019). Over the course of the PFT, 2102 km were driven, whereas on the VFT the hypothetical driven miles between each locality and to and from the accommodation which would have been required totalled 3955.2 km which is near double (188.2% increase) that of the VFT. This is the result of the localities being run in an ideal geological narrative order, in addition to localities in more distant localities being visited which were not reachable in the given timeframe of the PFT.

4.3 Cost

VFTs are known to be a cost-effective solution to field trips, as they reduce the financial burden associated with travel (Stainfield et al. 2000; Fletcher et al. 2002; Ramasundaram et al. 2005; Jacobson et al. 2009; Litherland and Stott 2012; Dolphin et al. 2019). The Utah 2021 VFT was no different, with no additional cost to each student compared to the normal working week.

Over the past five Utah PFTs, an average cost per student ranged between three to four thousand pounds (GBP), including flights, accommodation, car hire and national park fees which came directly from their tuition fees. This is a significant saving which has important implications for university budgets and the costs borne by students. The cost of PFTs can be a concern to students undertaking fieldwork which VFTs alleviate (Bond et al. 2022). It should also be noted that the cost savings do not include the cost of specialists' outdoor equipment which is often required for fieldwork.

4.4 Environmental Impact Analysis

VFTs are typically associated with lower carbon emissions (Schott 2017), mainly owing to the lack of long-distance travel. For the PFT, CO_2 emissions totalled 3.79 t per person through travel, including return flights and driven kms. A total of 38 t of CO_2 was generated for this trip, which was unusually low due to a small year group. In a normal year with between 20 and 40 students, it would be between c. 80 and 160 t.

For the Utah VFT, the CO_2 budget, including computer usage and commuting, was 0.0007 to 0.317 t per person. This range was controlled by the differing methods students used to travel to campus: walking, driving or public transport. Calculated CO_2 for staff and driving students for the duration of the trip was 0.93 t. CO_2 usage of computers produced a total of 0.0175 t. Estimates for the CO_2 of the cloud storage sites for the virtual outcrops were not available but are considered negligible, since the cumulative time spent serving a model is seconds per day. A total of 0.95 t was generated by the VFT, which is an average of 0.036 t per person, this is 1% of the impact of the PFT.

4.5 Learning Outcomes

The quantitative responses to the learning outcome section of questionnaires for the Utah 2023 PFT and 2021 VFT are plotted in Fig. 5. These are discussed in greater detail in Pugsley et al. (2022). The general question 'I learnt new concepts and material' was agreed with by 100% of participants across both trips, however, the interquartile range

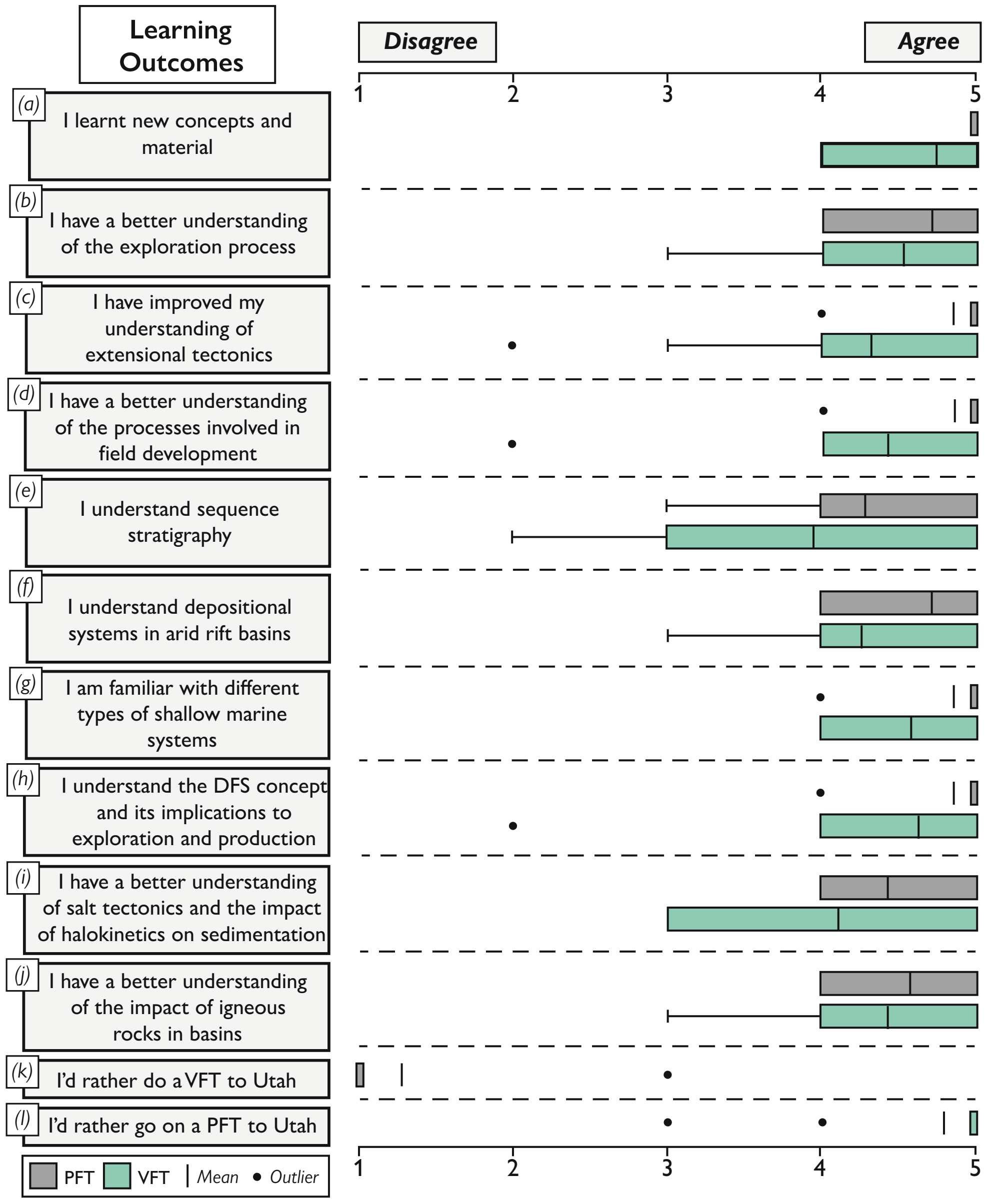

Fig. 5 Quantitative responses to the learning outcome section of questionnaires for the Utah 2023 Physical Field Trip (PFT) and 2021 Virtual Field Trip (VFT)

(IQR) for the PFT was broader between 4 and 5, whereas all students on the VFT selected 5.

For the specific learning outcomes students all agreed on the PFT that they had better understanding of hydrocarbon exploration processes with IQRs between 4 and 5, for the VFT the IQR was the same, but agreement was 89.5 and 10.5% responded with neutral (3). Again, all PFT student responses for understanding of extensional tectonics agreed 100% with an IQR of 5, whereas the VFT IQR varied from 4–5, with 84.2% agreeing, 10.5% neutral and 5.3% disagreeing. When asked about their understanding of the processes involved in field development the IGR for PFT again fell at 5, and all agreeing, whereas for VFT the IQR was 4–5, with 94.7% agreeing and 5.3% disagreeing. Student responses for their understanding of sequence stratigraphy showed the greatest range with PFT IQRs between 4–5 and 85.7% agreeing and 14.3% neutral, for the VFT the range was grater with the IQR between 3–5 and 68.4% agreeing, 26.3% neutral, and 5.3% disagreeing. The statement "I understand depositional systems in arid rift basins" had the same IQR range for both the PFT and VFT of 4 to 5, however, while 100% of PFT students agreed, for the VFT 84.2% agreed and 15.8% were neutral. PFT responses for familiarity with different types of shallow marine systems and understanding of the distributive fluvial systems (DFS) concept and its implications were identical with 100% agreeing, and an IQR of 5. For the VFT responses were also markedly similar with both having IQRs of 4 to 5, however, 100% agreed to the shallow marine statement, whereas 94.7% agreed and 5.3% disagreed to the DFS statement. For the understanding of salt tectonics and the impact of halokinetics on sedimentation the PFT IQR was 4 to 5, with 100% agreeing, whereas for the VFT the IQR was wider at 3 to 5, with 68.4 agreeing and 31.6 neutral to the statement. The final learning outcome specific statement 'I have a better understanding of the impact of igneous rocks in basins' has an IQR of 4–5 for both the PFT and VFT, with 100% of PFT responses agreeing, and 89.5% of VFT responses agreeing, and 20.5% neutral.

The PFT students also responses to the statement 'I'd rather do a VFT to Utah' the IGR was 1, with 85.7% disagreeing and 14.3% neutral. The VFT students were given the mirror statement 'I'd rather go on a PFT to Utah' and the responses where almost exactly mirrored with an IQR of 5 and with 94.7% agreeing and 5.3% neutral.

5 Discussion

This study evaluates efficiency of a like-for-like VFT and PFT to Utah and compares these findings to student perceptions of achieved learning outcomes. This evaluation provide data for those designing field trips to allow decision makers (e.g. trip leaders) to make more informed decisions, based on their unique circumstances. Efficiency can be evaluated in many ways. Here we present a method to quantify efficiency using time (duration analysis), logistics, cost, and environmental impact parameters. As a result, we found that VFTs are indeed significantly more efficient in all categories. The main VFT efficiency savings from our study are travel (e.g. less time spent in a car), more localities over a larger range following a geological narrative could be presented, and our VFT produced 1% of the CO_2 equivalent emissions to its PFT counterpart (largely owing to flights).

This study is not intended to be a discussion on the various merits of VFTs vs PFTs beyond efficiencies and learning outcomes. This has been covered elsewhere (e.g. Cliffe 2017; Dolphin et al. 2019; Pugsley et al. 2022; Smith and McNeal 2023). This case study VFTs was unquestionably more efficient in every metric recorded and that learning outcomes are comparable than the PFT. While we recognise that the sample size is small, especially for the PFT, we do not consider that this would have a significant impact on the efficiency metrics, as most such as cost, and CO_2 are directly scalable (e.g. 50 students will use 5 times as much CO_2 as 10). With respect to time, travel time is broadly similar regardless of the number of students. Differences in teaching/activity time for larger groups do exist and a larger group on the PFT would have been slower. This would have further increased the apparent efficiency of the VFT. However, efficiency, is not the only measure of a successful field trip, learning outcomes are also important.

The responses to the statements within the student questionnaire consistently illustrated that most students agreed they had improved their understanding across all the learning outcomes for both the VFT and PFT. Notably however, the PFT did consistently score higher, with the IQRs falling between 4–5 (agreeing), than the VFT which while most students did still agree, there was a broader range. Additionally, for the VFT there was one negative response on a couple statements. This potentially indicates students on the VFT generally felt slightly less confident in their knowledge than those who attended the PFT. Additionally, the larger range in responses for the VFT may illustrate a more varied experience, or potentially the less varied response of the PFT may owe to the small student cohort and small survey size. The largely positive VFT responses are in line with other studies on VFTs and learning outcomes (e.g. Sriarunrasmee et al. 2015; Klippel et al. 2019; Bond et al. 2022), overall learning outcomes were achieved according to student perception. Additionally, the assessed presentations were of a similar standard across both the VFT and PFT.

While PFTs are less efficient they have other benefits including increased social cohesion (Dunphy and Spellman 2009), emersion within the outdoor environment, nature, and travel (Bellan and Scheurman 1998) and financial benefits for local communities. They are also more significant "events" which students tend to remember often with positive association. Whilst less efficient, it is both likely and desirable that PFTs remain widely implemented within the geoscience curriculum. In the questionnaire most students indicated that their preference was a PFT to Utah, with only a couple individuals across both surveys responding neutrally to the statement indicating the choice between VFT or PFT. VFTs do appeal to some individuals, and they have a major role to play going forward, for individuals and groups that are unable to travel, to augment traditional classroom learning outside of scheduled field trips and as a mechanism to prepare students for or revise after PFTs. VFTs also potentially enable a higher number of individuals to attend (Stainfield et al. 2000; Dolphin et al. 2019) and participants to easily revisit localities to cement learning (Hurst 1998). Once constructed VFT's can be reused, in a similar way to field guides, such as the Utah 2020, being used in 2021 with minor adaptations reflecting the learnings from the previous year by staff. The VFT we present here are constructed using virtual outcrop collected by the authors and wider research team. There can be further efficiency gains from using pre-made freely available virtual outcrop from online repositories such as v3Geo and Sketchfab.

6 Conclusions

The VFT presented here in our case study was more efficient in all the categories, including time, logistics, cost, and environmental impact compared to its equivalent PFT. Learning outcomes were met to a similar level, gauged primarily through questionnaires. Generally, the PFT responses were less variable and marginally higher scoring but similar. The advent of VFTs has brought an improved flexibility. Future trips can benefit from a range of approaches with increased efficiency. However, multiple factors must also be considered when planning a field trip and the authors do not support or promote an abandonment of physical field trips. Instead, efficiency gains may made on PFTs through blending some VFT aspects. This study has provided a first attempt to quantify these efficiencies and compare them to learning outcomes, providing a framework for similar comparison elsewhere.

Supplementary Information The online version of this article (https://doi.org/10.1007/s41064-024-00321-y) contains supplementary material, which is available to authorized users.

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Author Contribution J.A. Howell, A.J. Hartley and J.H. Pugsley developed the virtual field trips 2020/2021 and ran the 2023 physical field trip. J.H. Pugsley and J.A. Howell wrote the main article draft. M. Chmielewska was responsible for processing most of the model data used across the VFTs. J.A. Howell, S.J. Buckley and N. Naumann conceptualized the VFT tools available in LIME, which were implemented the LIME team. N.J. Schofield and R. Brackenridge contributed to VFT and PFT. All authors read and gave input through multiple iterations of the article draft.

Availability of data and material Many virtual outcrop models presented in this paper are available on V3Geo (https://v3geo.com/, last access: 1 Dec 2021; V3Geo 2024). A data spreadsheet is supplied within supplement 1 for duration analysis, number of localities, and distance travelled.

Conflict of interest J.H. Pugsley, J.A. Howell, A.J. Hartley, S.J. Buckley, M. Chmielewska, N. Naumann, N.J. Schofield and R. Brackenridge declare that they have no competing interests.

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