Developing Virtual Field Experiences to Promote Student Learning and Bridge Knowledge Gaps between the Classroom and the Field in Undergraduate Geoscience Courses at the University of Waterloo

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

In 2020, a specific type of Virtual Reality (VR), Virtual Field Experiences (VFE), was identified as a proof-of-concept for positively contributing to student learning by the University of Waterloo's Department of Earth and Environmental Sciences (UW-EES). A pilot VFE was created and implemented in Earth 121 in the spring term of 2020. This successful implementation and constructive feedback from students and professionals established the basis for this thesis - improving the Earth 121 VFE for the following Fall 2020 term, in addition to creating another unique VFE for the Fall 2020 Earth 231 course. It was hypothesized that VFEs could be used to improve geoscience thinking of students and help students meet learning objectives during times when fieldwork was not feasible (as during the COVID-19 pandemic, in the case of Earth 231). The VFE implemented into Earth 121 was about salt and was designed to facilitate students' geoscience thinking, divided into four categories or ways of thinking: spatial, temporal, systems, and field (a foundational aspect of Earth 121). The VFE was a virtual tour, immersing students in 360° photospheres of specific environments related to the formation and use of salt. In Earth 231, a VFE was created using high-definition panoramic images of outcrops that were normally visited and mapped in previous terms in-person by students before the pandemic. In Earth 121, after having viewed the VFE, students were then asked to complete a salt quiz evaluating student knowledge and how students perceived their ability to think like geoscientists. In Earth 231, students in groups of five created a map and geologic interpretation of their assigned outcrop. This assignment and rubric remained mostly the same compared to previous terms, the only difference being the way in which students were able to gather information about their outcrop. Student performance data was analysed and revealed

that, in Earth 121, 91% of students felt they were able to think like geoscientists after viewing the VFE. The difference reported for each of the four ways of thinking was small, ranging between 42% and 49%. These results suggest that intentionally designed VFEs can help improve learning and specifically help students think like geoscientists, equally among the four ways of geoscience thinking in this case. In Earth 231, student overall marks were statistically similar to those from the fall term of 2019. Student marks in one specific area of the assignment, Map Elements, were statistically greater in the Fall 2020 term than the Fall 2019 Term. This suggests that students were able to meet the learning outcomes of the assignment, despite not being able to visit the field. Greater marks in the Map Elements section are likely due to an added lab exercise in the Fall 2020 term, where students were able to practise creating map elements before the outcrop assignment, something not done in the Fall 2019 term. This thesis has demonstrated that intentionally designed VFEs contribute positively to students learning in undergraduate courses at the University of Waterloo. VFEs help students develop their geoscience thinking and can be used to support assignments with field components that are temporarily not feasible. VFEs are an emerging technology that can be further used to help bridge the gap between the class/lab and the field and educate students to become more competent geoscientists.

Acknowledgements

I would like to thank Dean of Science Dr. Bob Lemieux for providing the funding and opportunity to work with the Department of Earth and Environmental Sciences, exploring the design and implementation of VFEs. Not only did funding from the Dean's Undergraduate Teaching Initiative allow me to develop a thesis using some amazing emerging technology, it also allowed me to work with the department as a co-op student; an experience for which I am very grateful.

I would like to thank Dr. John Johnston and Dr. Jen Parks for supervising my thesis. Both Jen and John have provided invaluable insight and guidance towards the completion of this thesis. Thanks to their support, I have been able to develop my geoscience knowledge and my academic writing skills. I am very grateful to have had the opportunity to work for both Jen and John and to have learnt so many things that I can use beyond my undergraduate career. Thank you both.

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1.0 Introduction

As existing technology improves and new technology emerges, there is a great opportunity to further integrate technology into geoscience education with effective pedagogy. This thesis examined the effectiveness of one such emerging technology, Virtual Reality (VR), on improving students' abilities to achieve the learning outcomes of two undergraduate geoscience courses at the University of Waterloo (UW). In late 2019, UW's Department of Earth and Environmental Sciences (UW-EES) received funding through the Dean's Undergraduate Teaching Initiative (DUTI) to explore the implementation of VR into geoscience courses. This funding and opportunity to improve undergraduate education in the Faculty of Science at the University of Waterloo was provided thanks to the Dean of Science, Dr. Bob Lemieux. One common type of VR refers to a simulated environment that can be viewed in 360° with a VR headset. The immersivity of the VR experience is usually directly related to its cost and can be quite high. There are, however, less expensive methods for using VR. To balance cost and effectiveness teaching of undergraduate geoscience students at UW-EES, a Google Expedition Kit was purchased with DUTI funds, which outfitted up to 20 students to view and guide VR Tours (assemblages of individual 360° pictures known as photospheres). The Google Expedition Kit was chosen as a relatively low-cost, proof-of-concept option to test the effectiveness of VR in undergraduate geoscience courses for improving student learning. Virtual Tours were designed around specific geoscience course and module learning objectives for Earth courses offered in 2020 Spring and Fall terms. This was done to provide students with a Virtual Field Experience (VFE) which transports students to locations inaccessible for a class, helping connect what a geoscientist would observe while immersed in the field to concepts learnt in the classroom or lab. After viewing Tours, students were asked about their perceived improvements to their learning and geoscience knowledge. Students overwhelming perceived improvements to their learning and geoscience knowledge, particularly in their spatial thinking skills. This served as a valuable proof-of-concept for Virtual Reality application in geoscience education, demonstrating that Virtual Tours can be used to increase students' abilities to think like geoscientists. This thesis explores the introductory application of VFEs in undergraduate geoscience courses at UW-EES.

The development and integration of this emerging technology using the Google Expedition Kit in class and labs changed when the COVID-19 pandemic forced in-person approaches to pivot to a remote approach starting in the end of the 2020 Winter term. Although this unfortunate circumstance prevented the continued use of the Google Expedition Kit in classes and labs, it provided an opportunity to further apply and develop uniquely crafted student-guided Tours in remote settings. Because the majority of classes offered by UW-EES became remote offerings in the end of the 2020 Winter term and fully remote in 2020 Spring and Fall terms, further exploring this new approach using VFEs in many remote classes and labs became more important to support student learning. The author of this thesis was hired as an emerging technology research assistant (a co-op student-funded position through the DUTI) before this thesis commenced and before the pandemic. This was critical in establishing the groundwork for selecting, viewing, creating, editing, and integrating VFEs into geoscience education at the University of Waterloo. This happened to be timed with the start of the global COVID-19 pandemic and helped successfully pivot the use of VFEs in remote learning. This combined experience helped provide a unique opportunity to also explore the creation of VFEs by instructors and students to enhance student geoscience learning, especially during a pandemic when classes are remote, travel is limited, and people are striving to connect.

2.0 Literature Review

2.1 Context

A vision of implementing VR into geoscience education at UW-EES was in a successful proposal for the Dean of Science Undergraduate Teaching Initiative in 2019. A part of this funding included purchasing a Google Expedition Kit and implementing this technology into geoscience classes and labs with help from a University of Waterloo co-op student. The author of this thesis was fortunate to secure this co-op position during the 2020 Winter and Spring terms. This established the foundation and idea to pursue an undergraduate thesis investigating the impact of a specific type of VR, VFEs, to student leaning in three classes during 2020 Fall term. To understand the basis for this new avenue pursued in this thesis, two publications presented before this thesis must be described. The publications were posters describing emerging technologies (Visneskie et al., 2020a) and the integration of VFEs in geoscience undergraduate education (Visneskie et al., 2020b). This provided a comprehensive base to understand the bridging of new technology and geoscience education required to improve training of future competent professionals.

VR in postsecondary education offers many benefits, such as bridging knowledge gaps between the classroom and field, increasing interest and engagement, and preparing for field work, as described in Visneskie et al. (2020a). Some challenges were found while piloting the use of Tours in class and labs, such as visual distractions in the Tour or motion sickness from the relatively simple VR viewers, however it was found that many challenges can be mitigated with intelligent design of Tours. A major advantage of using Google Expedition Tours are the variety of already tested resources available to create VFEs easily and at no cost (Visneskie et al 2020a). The second publication (Visneskie et al. 2020b), completed at the end of the 2020 Spring work term demonstrated that intentionally created VFEs that were aligned with course objectives had facilitated perceived sudden moments of comprehension and increases in geoscience thinking. However only two weeks at the end of the 2020 Spring term and co-op work term were used to analyse results collected from implementing a specific Tour in a large online class during the start of the pandemic. Preliminary results and interpretations were presented in Visneskie et al. (2020b) but it was recognised that a comprehensive analysis was needed to understand the full potential of VFEs in geoscience education. A significant amount of the 8-month 2020 co-op work term was used to compile many different research papers on emerging technologies and geoscience education, providing foundational knowledge of VR in the context of student learning, including its implementation challenges, benefits, best practices, hardware, and software. During these preliminary investigations and piloting use of the newly purchased Google Expedition Kit, a best practices guide was created formed the basis for creating a new assignment for a class in 2020 Fall term. So, work completed in the co-op work term established a comprehensive foundation to implement VFEs into UW-EES classes and labs and test their effectiveness. All the research and experimentation during the co-op work terms allowed for a targeted literature review in this thesis, which has been organised into two categories that are described in the next two sections, namely the development of geoscience-related skills and how VFEs can be tailored to achieve different learning outcomes.

2.2 Geoscience-related skills developed using VFEs

In order for Virtual Field Experiences (VFEs) to effectively support students' development of skills such as logical thinking, reasoning, and problem solving, the VFEs must be designed with strong geoscience pedagogy in mind (Sriarunrasmee et al., 2015; Seifan et al., 2019). VFEs can also be used to prepare students for field work, invoking more confidence and a greater understanding of geologic features (Seifan et al., 2019; Chenrai and Jitmahantakul, 2019; Cliffe, 2017). Additionally, in order to be effective, VFEs require the same amount of planning as traditional field trips (Seifan et al., 2019). It is also important to consider the presentation of a VFE. By creating a virtual tour that addresses learning at two levels (a basic knowledge level and a more critical, metacognitive level), student learning performance, achievement, motivation, self-efficacy, and problem solving are improved (Litherland and Stott, 2012; Meyer et al., 2019; Carbonell-Carrera and Saorín, 2017). Visneskie et al. (2020b) determined that VFEs can be used to help students develop their spatial, temporal, systems, and field thinking. VFEs are also effective in eliciting sudden moments of comprehension, insight, and/or understanding about concepts within the Virtual Tour (Visneskie et al. 2020). Rogers (2020) conducted a study to determine how photospheres (360° photos or panoramic images that provide an immersive background environment) contribute to student learning. Twenty undergraduate geoscience students were asked to interpret rock samples, aided by a photosphere of the outcrop from which the sample was collected. The study contained questions asking students about the influence of these photospheres on their ability to complete the assignment. Figure 1 shows student responses to five questions in Rogers (2020). In all questions, the majority of students felt the VR component provided additional information about their rock sample, influenced their description, and influenced their overall interpretation of the rock's environment. Figure 2, also from Rogers (2020) demonstrates how useful students ranked photospheres when making geological investigations. Students concluded overall that the use of VR photospheres provided them with a better understanding of outcrop morphology and depositional environment related to the samples.

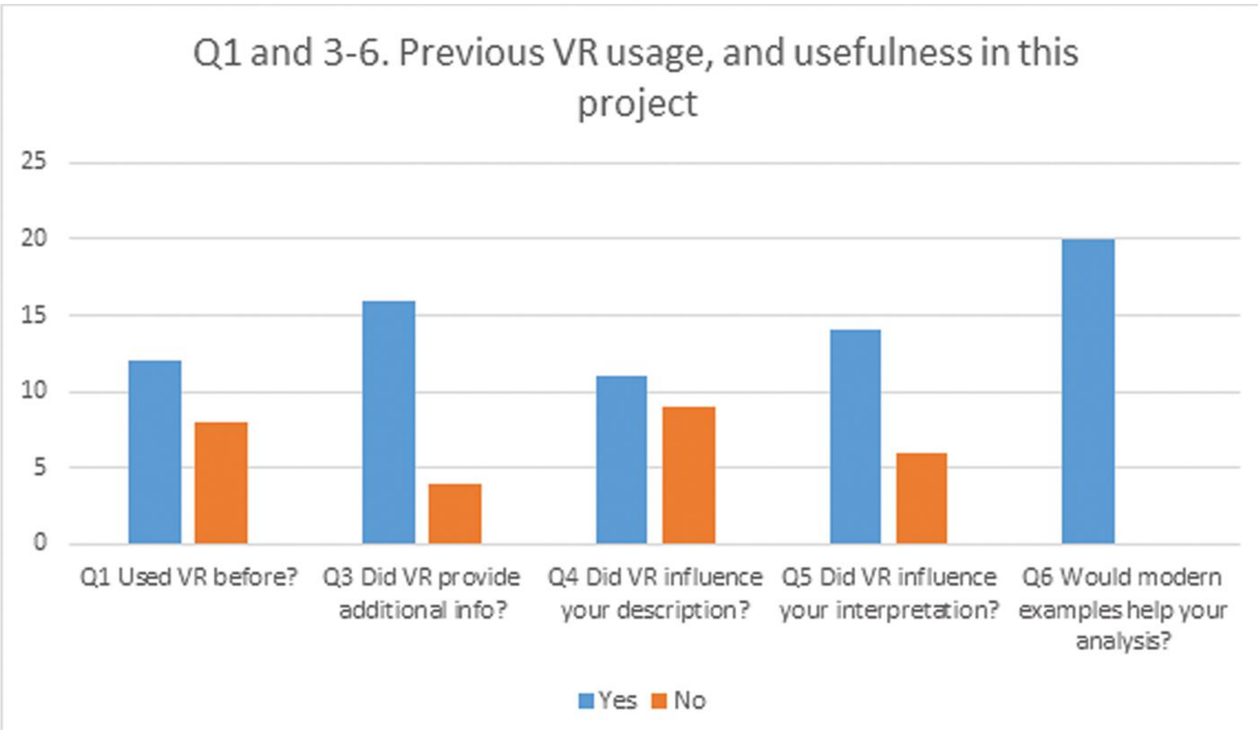

Figure 1. Student's perceptions of the impact of VR photospheres as a tool for describing and identifying rock samples (modified from Rogers, 2020)

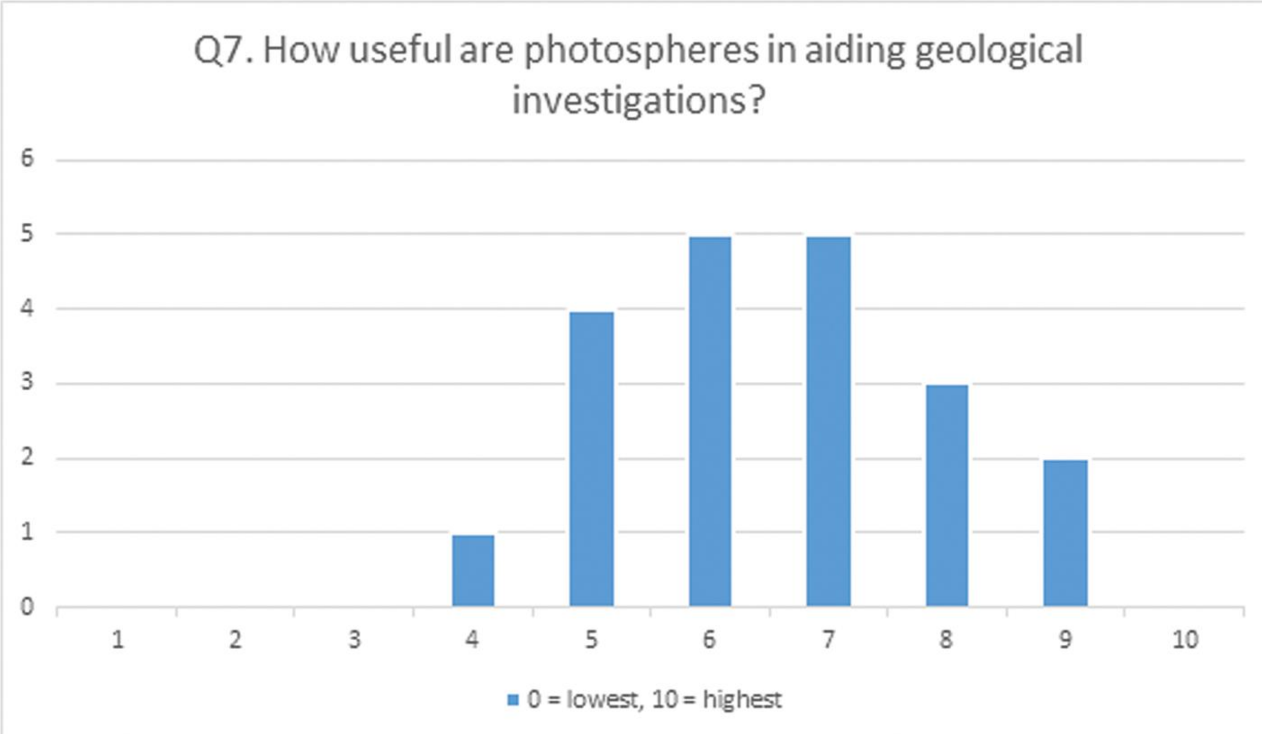

Figure 2. Utility of VR photospheres, as ranked by 20 students, for conducting geological investigations (modified from Rogers, 2020)

2.3 Modify VFEs to achieve learning outcomes

Using VR as a tool for student learning is advantageous as students have a positive opinion of this technology and perceive it as more interesting than conventional teaching methods for learning about locations (Carbonell-Carrera and Saorín, 2017; Cliff, 2017; Rogers, 2020). It is crucial to note that virtual reality can only be a complement to existing in-person field trips; it is not suitable as a replacement (Cliff, 2017; Litherland and Stott, 2012; Dolphin et al., 2019). There are also many ways VFEs can be used to effectively target learning outcomes such as in combination with lectures or assignments, to prepare for field work, or to review key information post-field work (Minocha et al., 2017; Dolphin et al. 2019; Kingston et al. 2012; Cliffe, 2017) In general, there appears to be trade-offs when using virtual reality as an educational tool. When it comes to learning technical knowledge, virtual reality is less effective than a slideshow, but more engaging, interesting, and motivating to students (Parong and Mayer, 2018). When students are guided through a virtual Tour by a teacher, they retain more information from the Tour than if they explore the Tour autonomously (Tutwiler et al., 2013). However, students are more engaged and excited about virtual reality if they are able to guide themselves autonomously (Tutwiler et al., 2013). Therefore, the goal is to retain the engaging nature of virtual reality, while using intelligent educational design to facilitate learning (Parong and Mayer, 2018). Google Tour Creator is an effective website for creating free Virtual Tours, hosted on Google's Poly website: https://poly.google.com/. The Tour Creator has different components that can be tailored to specific learning objectives: the photospheres, the Scene descriptions (text which provides context for the overall Scene), and the Points of Interests (markers that denote important locations or features within the photosphere (Visneskie et al., 2020a; Visneskie et al., 2020b). When selected, POIs reveal specific text information and/or 2D images. Tours can be propagated to an entire class and teacher-guided, or they can be downloaded by students and self-guided. Instructors using the teacher-guided method are also able to direct the attention of viewers to specific areas of photospheres and use a drawing tool to draw over the photosphere when guiding. Tips for effectively designing these virtual Tours were compiled from various published sources into a single creation guide by Visneskie during the 2020 co-op term. The COVID-19 pandemic prevented the use of the teacher-guided functionality (initially piloted in classes during the Fall 2020 semester), further justifying the exploration and support of the self-guided functionality to accommodate remote learning.

3.0 Hypothesis

Integrating VFEs into first- and second-year geoscience courses at UW-EES will help students better achieve course learning objectives and better develop student geoscience knowledge required for professional competency. Replacing a class fieldtrip and group assignment with a VFE will improve student performance on the respective assignment, due to the more guided nature of VFEs compared to student explorations while in the field.

4.0 Objectives

The overall objective of this thesis is to evaluate the effectiveness of VFEs in select undergraduate geoscience courses in the Department of Earth and Environmental Sciences at the University of Waterloo. It is predicted that after having students view or create and view VFEs they will improve their ability to achieve course learning objectives, geoscience knowledge, and understanding of the field. VFEs are predicted to help students bridge gaps between classroom/lab and field knowledge but should not replace field work, rather help prepare for field work. VFEs are predicted to be very useful to address challenges associated with travel restrictions during the COVID-19 pandemic. Objectives for specific courses investigated in this thesis are shown below.

4.1 Earth 121: Introductory Earth Sciences

- Students will view a VFE about salt, designed to intentionally align with course learning objectives, which will help students think like geoscientists (a foundational course learning outcome). Students will report increases to their systems, spatial, temporal, and/or field thinking – ways of thinking used by geoscientists, as outlined in Earth 121: Introductory Earth sciences.

4.2 Earth 231: Mineralogy

- In Earth 231: Mineralogy, students will successfully complete a traditionally field-based geologic mapping and interpretation assignment using a VFE, designed to emulate a traditional field experience. This will also present a proof of concept of VFEs being used to convey specific field-based information, which was not feasible due to travel restrictions during a pandemic.

5.0 Methods

Different methods were applied to the two UW-EES courses during the 2020 Fall term, including the VFEs, assignments, implementation, and analyses in each course. To help compare and differentiate methods applied in these two classes, Tables 1 and 2 are presented below that outline the process used to conduct the research which constitutes this thesis. This process is subdivided into three parts – the VFE design, the assessment of the VFEs, and the analysis of the VFE data.

5.1 VFE Design

VFE implementation was different for the two courses, designed to specifically align with intended learning outcomes of each course. A summary of the different design aspects of the VFEs implemented into each course are shown in Table 1.

Table 1. Summary of information related to the design aspects of VFEs implemented in Earth 121 and 231.

VFE Components	Earth 121	Earth 231
Creator	Thesis author, Henry Visneskie	VFE created by instructor Dr. Jen Parks and TA Quinn Worthington
Type of VFE	Virtual Tour of salt-related environments	High-definition panorama of three Bancroft, Ontario outcrops
Elements included	Contains Scenes with 360^{o} photospheres and POIs (text, 2D images)	Contains a panorama with POI area markers and text, as well as individual close-up pictures and a video demonstrating an HCl test
Method of Evaluation	Student knowledge and perception evaluated in a quiz, after tour was viewed	Student map creation and outcrop identification evaluated with an existing rubric

The VFE design stage was very important and was completed before and while VFEs were being created and before they were integrated into the two courses. Due to the difference in course content, the VFE design was unique to each course. For Earth 121, a Virtual Tour (one type of VFE) was designed for students to view as part of a newly created assignment. The Tour was created using specifically chosen photospheres from locations available in Google Street View around the processes that contribute to salt formation and the ways in which humans interact with salt, as it relates to the Earth 121 Resources unit. Each Scene (using either a photosphere or panoramic image as the background) contained between three and five POIs. These POIs, accompanied by text and/or 2D images, were used to sequentially direct the viewers' attention to specific sections of the Scene. The text and images associated with the POIs provided further context to specific areas in the 360-degree photosphere. An example of one of these Scenes can be found in Figure 10, at the beginning of Appendix A. A learning objective was established for each Scene, in order to design the Tour in a way that contributed to the overall learning objective for the Salt VFE. The number of Scenes and POIs were created intentionally to provide enough detailed information while not being extraneous for students to work through.

Overall, the Salt VFE was designed to facilitate students' ability to think like a geoscientist. The virtual Tour can be found here: https://poly.google.com/view/9PgvVP1dhBq. Because geoscience thinking is comprised of spatial, systems, field, and temporal thinking, different design elements were included to cater to each of these. For example, a photosphere from Utah's Great Salt Lake was used for the first Scene of the Virtual Tour. This photosphere, along with a diagram displaying the process of evaporation, was used to contextualise the many different processes that are involved in salt formation, invoking students' systems thinking. The Goderich Mine was chosen for the second Scene of the Virtual Tour to give students a better understanding of the depth, scale, and dimension of salt mines, prompting students to think spatially or in 3D. This was further supported by a 2D image overlay depicting a simple cross-sectional diagram of room and pillar mining. This photosphere in the second Scene was also selected because of the visible strata within the mine, to which students were able to apply the Principle of Superposition and consider the amount of time for such strata to occur, prompting students to apply temporal, spatial, and field thinking. The third photosphere, depicting the overground mining facility, provided students with a simplified diagram of the underground mining operation as well as information about salt processing and shipping. This Scene allowed students to primarily demonstrate their systems and field thinking. A panoramic image was selected as the background for the fourth and final Scene in order to summarise the relation and relative order of salt formation processes from the modern environment to ancient deposits and human uses. This panoramic image was used to summarise and connect each of the four types of thinking. The components of this final Scene included showing the depth of the Goderich Salt in a cross-section of the regional geology (spatial), the connection of processes of precipitation, sedimentation, and lithification explained and demonstrated with images (systems), the cyclical nature and time of salt formation shown using arrows (temporal), and the ways in which geoscientists interact with the environment, supported with 2D images and text (field). This variety and placement of design elements was critical for creating a VFE that would prompt students to use and develop their spatial, systems, field, and temporal thinking.

The VFE implemented in Earth 231 was intentionally designed to provide students with the resources needed to complete a traditionally in-person field assignment, online. Prior to 2020, groups of students would visit, map, and interpret one of several outcrops. The 2020 assignment outline can be seen in Figure 11 and the 2019 assignment outline can be seen in Figure 15, both in Appendix B. Due to travel restrictions imposed by the COVID-19 pandemic, Dr. Jen Parks and Teaching Assistant Quinn Worthington created a VFE with high quality panoramic images of three outcrops in order to allow students to zoom and pan throughout the outcrop, virtually. Additionally, POI markers were placed throughout each outcrop panorama, in order to provide students with key information that could only be discerned in-person, with mineral properties such hardness. In addition to these detailed panoramic images, students also had access to the Google Street View location and a detailed geologic map of the region. All of these resources are included in Appendix B, within the Fall 2020 Outcrop Resources section (Figures 12 and 13). Students were also provided with more than 20 close-up images of their outcrop, as well as a short video, demonstrating HCl dissolution tests.

Students were assigned, in groups of four or five to one of three outcrops – a skarn outcrop, pegmatite outcrop, or carbonatite outcrop. Using the virtual resources provided, each group was required to write a geological report and make a short presentation about their assigned outcrop. This included describing their outcrop in the context of the surrounding regional geology, the creation of a geological map for the outcrop, as well as an interpretation of how the outcrop formed. The assignment expectations were established similarly to previous years, the primary difference being the creation and implementation of virtual outcrop resources (see Earth 231 2019 and Earth 231 2020 assignments in the appendix for comparison). The assignment outlines from both years can be found in Appendix B.

5.2 Assessment of VFEs

Many considerations must be made when creating a VFE, including how its effectiveness will be assessed. A summary of details about how the VFE effectiveness is assessed is shown in Table 2. The Table explains how students were involved in determining the VFE effectiveness in each of the courses (i.e., what students were expected to do). Rubrics and quizzes are discussed further below.

Table 2. Methods involved in assessing the effectiveness of each course's VFE

Assessment Component	Earth 121	Earth 231
Evaluated student work	VFE quiz with knowledge-based matching questions and short answer, experience-based questions	Term project testing students on rock identification, outcrop interpretation, map creation, presentation using VFE panorama
Type of work and weight of overall mark	Quiz worth 3% of total class grade	Group project worth 25% of total class grade
Method of assessment	Automatically graded rubric based on correctness for matching questions and quality participation for short-answer.	Rubric (also used in previous terms) assessing student competency in multiple criteria, completed by instructor, Dr. Parks.

5.21 Earth 121

In Earth 121, students completed a quiz worth 3% of their overall grade based on information from the Salt Virtual Tour. The quiz contained four questions. The first two were knowledge-based questions that directly address the content of the Tour and the third and fourth were short answer questions which assess students' perceived change in their ability to think like geoscientists. A core learning outcome of this course is for students to think more like geoscientists, which is divided into four main categories of thinking, defined in Earth 121 as:

- Spatial thinking (accounting for geologic relationships and processes at micro, meso, and macro scales, in 2D and 3D)
- Temporal thinking (using time as a way of describing and comparing geologic relationships and processes)

- Systems thinking (how the atmosphere, hydrosphere, geosphere, and biosphere interact with one another to create geologic processes and materials)
- Field thinking (using multiple senses to make robust observations and interpretations in the virtual or physical world)

Question 1 asked students to match definitions of key geologic terms related to the VFE to the correct geologic term. This knowledge-based question was used to assess students' understanding of key information from the VFE. Table 3 lists the terms and their corresponding definitions.

Table 3. Question 1 geologic term prompts and definitions available for matching

Geologic Term	Definition
Evaporite Deposits	Nonmetallic mineral resource
Silurian	Geologic time period in which salt formed
Superposition	Stratigraphic principle used to determine relative age of salt layers.
Goderich	Location of world's largest underground salt mine containing ancient salt deposits.
Dead Sea	Modern environment where salt forms.
Chemical Sedimentary Rock	Rock salt is classified as this type of rock.
Halite	Common mineral found in rock salt.

In the Earth 121 quiz, question 2 was an additional knowledge-based question following question 1, which asked students to order the following processes that contribute to salt formation: Saltwater Input, Water evaporation and Salt Precipitation, Sediment Deposition, Lithification and Burial, and Rock Salt. The first short answer question (question 3) in the Earth 121 quiz asked students, "After having viewed this Virtual Reality (VR) "Salt" Tour, do you feel as if you've gained a greater understanding of what it means to think like a geoscientist? If so, please describe how this new Tour improved your spatial, temporal, system and/or field thinking". Question 4 in the Earth 121 quiz asked, "While you viewed this new Salt Tour did you experience an "aha" moment or a moment of sudden realization, inspiration, insight, recognition, or comprehension? If so, please describe this moment and how the VR Salt Tour facilitated this moment". Question 3 was created to gather insight about how students perceived the impact of the salt VFE on their learning and question 4, to gather insight about sudden moments of comprehension students experienced that were a result of the VFE.

5.22 Earth 231

Earth 231, students completed an assignment that normally involves a field trip to an outcrop in Bancroft, Ontario. The assignment (which required students to map and make geologic interpretations of an outcrop) remained the same, however (due to the COVID-19 pandemic) the field trip component was substituted with a VFE. The results were used to determine how student results are impacted when physical field components of an assignment are substituted with a VFE. Each group was marked using an already existing assignment rubric. The rubric has received almost no changes from previous years so that it could help evaluate the virtual nature of the assignment compared to in person experiences in previous years. The rubric is divided into multiple weighted categories, detailed in Table 4 below. The 2020 and 2019 rubrics are included in Appendix B, as Figures 14 and 16, respectively.

Table 4. Earth 231 rubric criteria categories, by section and weight

Category	Subcategory	Weight (out of 60 marks)
Presentation	Oral communication skills/creativity	2.5
	Outcrop map	2.5
	Scientific content	2.5
Report format	Format	2.5
	Writing style, spelling and grammar	2.5
Referencing	Type/appropriateness	2.5
	Paraphrasing, use of in-text references	2.5
	Format	2.5
Report	Report : general presentation of data, depth and breath	5
Topic rocks	Review and description of your topic rocks	5
Regional geology: Grenville	Description of Grenville	2.5
	Map of Grenville	2.5
Local geology: around your outcrop	Description	2.5
	Local map	2.5
Your outcrop	Description of rock units and outcrop	5
Outcrop map	Map elements	2.5
	Unit subdivision/accuracy	2.5
Geological history	The story from your outcrop	5
	Scientific support and/or connection to Grenville	5

5.3 Data Analysis of VFE data

Analysing and interpreting experimental data is crucial to determine the impact of the VEFs in Earth 121 and Earth 231. Table 5 below describes the similarities and differences of each course's data analysis. This includes the type of data obtained from each course and how the data is organised.

Table 5. Types of data collected from each course as well as methods of analyses

Data obtained	Earth 121	Earth 231
Type of data	Qualitative data obtained from short answer quiz questions. Similar responses grouped to determine the types of learning the Tour facilitates. Quantitative data obtained from knowledge-based questions used to determine what information was effectively conveyed with the Tour	Quantitative data obtained from students' grades in each section of the assignment rubric. Data used to determine student performance; compared to data from the assignment in previous terms to determine statistical impact of a VFE versus a field trip
Subdivisions of data	No subdivisions amongst class	Subdivided by outcrop group, by class year, and by sections of the rubric

In order to determine the impact of the Virtual Tours in each of the courses, data from each course was analysed. The quiz Earth 121 students completed, regarding the Virtual Tour content, provided both qualitative and quantitative information. Students' responses to the knowledge-based questions quantitatively demonstrated how much information students learnt from the Tour. Students' responses about improvements to their geoscience thinking and sudden moments of insight provided qualitative information about students' experiences with the Virtual Tour. These responses were grouped to determine how effective Virtual Tours were for contributing to the different categories of thinking. For example, maybe they contributed overwhelmingly to only Spatial Thinking. Perhaps there is more variability, and Virtual Tours can be used to develop multiple types of thinking.

Quiz data was exported from the University of Waterloo's course management website Learn and organised to evaluate each question. Question 1 responses were filtered according to whether or not the student correctly matched a definition to the corresponding VFE-related term. For each match, a value of 1 was added in a "Score" column in the same row. The score sum was computed for each student, providing the number of matches each student got correct out of 7, the total number of matches in question 1. This data allowed for analysis of individual student performance. For collective student performance, the number of times a definition was assigned to each term (correct or not) was recorded. This demonstrated what the most common definitions chosen were, for each term. Question 2 data was not analysed due to the difficulty associated with organising and interpreting it. There was no clear way to determine which processes students ordered incorrectly, as they were all relative to one another. Additionally, the value of knowing which students made one mistake in the order compared to two mistakes was not clear. Questions 3 and 4 were analysed similarly. As these questions were short answer, student responses varied and hence required codification. Using the Earth 121 definitions for each of the four ways of thinking, categories were identified in which to sort student responses. These categories were determined uniquely for both question 3 and question 4 responses, although they share similarities. Students who responded received a 1 in each category they mentioned. The results were tallied to determine the distribution of where students felt their thinking improve as well as moments of insight/comprehension they experience. These results helped determine the types of thinking which VFEs can facilitate as well as whether or not VFEs can be used to help students think like geoscientists.

Students in Earth 231 were assessed by the course instructor quantitatively in the rubric for the assignment and evaluated in this thesis by using statistical analyses to compare assignment marks from this term (using a VFE) to previous terms (using a physical field trip). The marks for 13 student groups in 2019 and 18 student groups in 2020 were recorded in an Excel spreadsheet after exporting from the University of Waterloo's Learn website. All marks were converted to percentages, in order to normalise the information. The first comparison made was between the groups of each year (e.g., 2019 skarn and 2020 skarn student groups). This was done by performing Welch's t-test in Excel, which in addition to revealing the mean and variance of the datasets, also determined if the datasets were statistically similar to one another (that is, any variation can be attributed to randomness and not a specific influence). The overall grades between the 2019 and 2020 classes were compared as well, without evaluating each individual student group studying a specific outcrop. To determine if any of groups performed statistically differently on individual categories of the rubric, six rubric categories were identified as being more likely to have been affected by transition to an online assignment. Specifically, these sections were directly impacted by students' abilities to gather information from their outcrop. Due to the change in how this information was obtained and interpreted by students (in-person compared to using the VFE), the rubric categories which consider information collection and interpretation were identified as areas of potential change as well. These categories are as follows:

Table 6. Categories likely to be most affected by the change in outcrop information collection and interpretation, as determined by the thesis author

Local geology: around your outcrop	Description	2.5
	Local map	2.5
Your outcrop	Description of rock units and outcrop	5
Outcrop map	Map elements	2.5
	Unit subdivision/accuracy	2.5
Geological history	The story from your outcrop	5

By testing to see if different populations are statistically similar, conclusions can be made about the effectiveness of VFEs for conveying specific learning objectives. In Earth 231 specifically, comparing different sets of data from different years will reveal if certain populations perform differently when comparing the assignment online to in-person. From this, interpretations will then be proposed.

6.0 Results and Interpretation

Based on the methods conducted in Earth 121 and Earth 231, qualitative and quantitative data was collected and analysed in order to determine the impact of VFEs on student learning in these courses. The analysed data from each course is explained more thoroughly in the corresponding course subsections below and visualised using graphs and Tables, in addition to text descriptions. The Earth 121 section describes the results of the matching question (question 1), and the two short-answer questions (questions 3 and 4). The Earth 231 section compares the results of student performance between years, between outcrop groups, and between different sections of the assignment rubric.

6.1 Earth 121 Introductory Earth Sciences

This section is based on the associated Salt VFE, which can be found here: https://poly.google.com/view/9PgvVP1dhBq. The many customisable elements within the VFE were designed in such a way to contribute to the development of geoscience knowledge of Earth 121 students. An example of a VFE Scene with some different design elements is included in Appendix A.

6.12 Knowledge-based Matching Question Data

The first set of data collected was from the 353 students that attempted the knowledge-based matching question in Earth 121 during the 2020 Fall semester. Students were provided a number of geologic term prompts and an equal number of geologic definitions, each only to be used once. Students were required to match the definitions to the prompts. The matches of students to each of the seven prompts were analysed to determine how many times each definition was matched with each prompt. For quiz question 1 in Earth 121, the two most common matches selected by students for each of the seven prompts is shown on the x-axis in Figure 3. The correct answers for each prompt are indicated by the responses which labels the green or lower part of bars. Incorrect answers for the listed prompts are represented by red bars, atop the bars. The height of the bar (y-axis) corresponds to the percentage of students which selected the associated response in a matching quiz. From Figure 3, it is clear that the majority of prompts were matched correctly by the 353 students who answered the question. The prompt with the least number of correct matches, “nonmetallic mineral resource”, was matched correctly by 71% of students. The most matched prompt, “Stratigraphic principle used to determine relative age of salt layers” was matched correctly by 99.4% of students. It is important to note that the two most common responses shown in Figure 3 sum to less than 100%, as the remaining five prompts constitute the percentage difference. The raw data used to create Figure 3 is found in Table 9 in Appendix A.

This difference of almost 30% between the most and least correctly answered prompts may be attributable to two factors – firstly, the design of the Salt VFE may have better conveyed the Principle of Superposition to students, allowing them to better retain information about it. Alternatively, the ambiguity of the prompts and responses may have caused students to match more accurately some of the options compared to others. In fact, the prompts most correctly answered are those with matches that are unique proper nouns (i.e., Superposition, Silurian, Goderich). Comparatively, the prompts least correctly answered are those with more widely applicable terms (i.e., evaporite deposits, halite). This discrepancy could explain why students were more likely to correctly match some prompts rather than others. An additional implication is that students may need better clarification between rock, minerals, and deposits. The reason is likely a combination of the two previously mentioned – because students are unclear on rocks, mineral, and deposits, they are more likely to correctly match definitions corresponding to unique proper nouns.

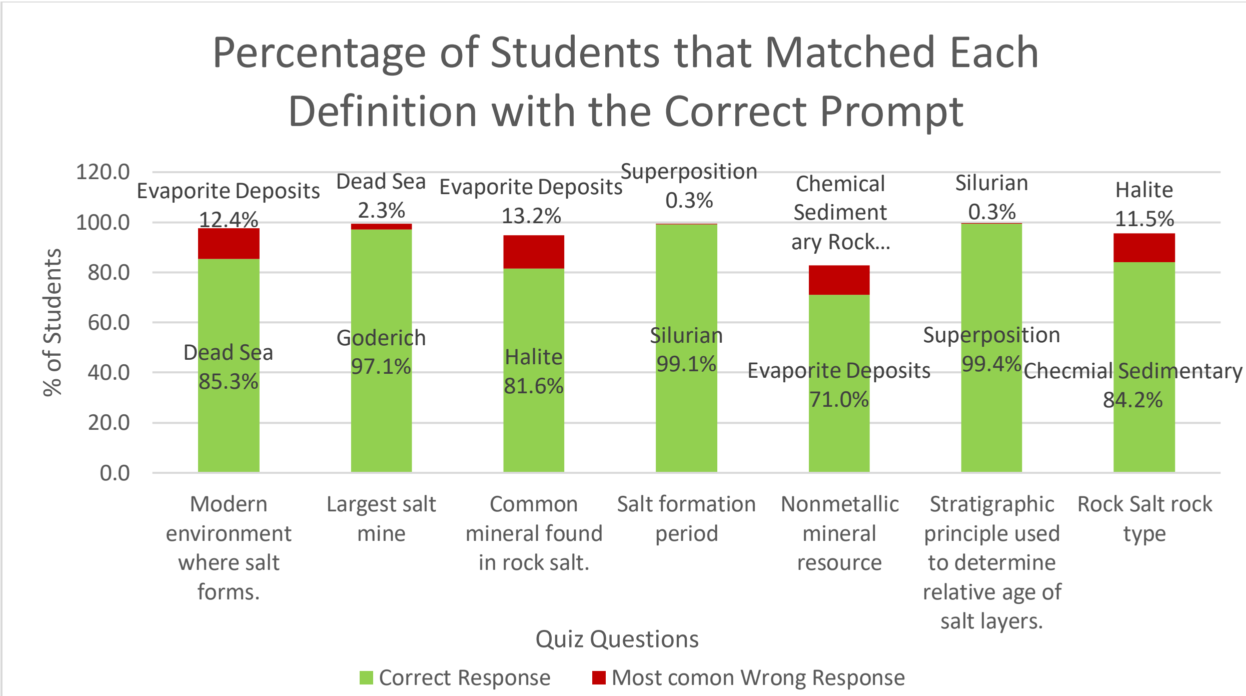

Figure 3. Proportion of students which correctly matched each term and corresponding response (in green or bottom boxes in each cumulative bar) as well as the most commonly selected incorrect match (in red or top boxes in each cumulative bar).

The distribution of correct responses can be visualised by the frequency of student scores as well. Figure 4 shows the overall distribution of the number of correct matches made by students, out of seven possible matches. The bar graph indicates that 65.8% (n = 229) of students correctly matched all seven responses with their corresponding prompts in the matching quiz. Populations of data such as grades are sometimes considered normally distributed, however the data in Figure 4 suggests skewed results in terms of overall student score for the matching quiz. This may be a result of a combination of factors. For example, because each response was only to be matched to a prompt once, and all responses were to be used, students that were confidently able to identify a match were also eliminating the opportunity to make an incorrect match. For example, if a student was able to correctly identify that “Goderich” should be matched with “World’s largest salt mine”, the student would be able to remove the response “Goderich” from consideration in another match, if they were to guess the correct response by chance. This result could also be attributed to the level of difficultly of the matching or the effectiveness of the VFE. Perhaps the matches were simply too easy for students to make and/or perhaps the VFE was exceptional at teaching students about the matching terms. The raw data used to create Figure 4 is found in Table 10 in Appendix A.

Some other notable information is that every student made at least one correct match. Additionally, there seems to be very few people who achieved a score of 6 out of 7. This may be due to the effect mentioned earlier, where each response is only matched once and making a confident match removes a response from consideration in other matches. In other words, as students worked their way through matching the responses, the pool of available responses became smaller, making it easier to identify the correct one. If a student had made 6 correct matches, the 7th remaining response would have to correspond to the only unmatched prompt. The only way around this would be if a student was not confident in their response for two prompts and chose to answer both with the same response. This would ensure the student got one of the prompts wrong and one right, making it possible for a student to achieve a score of 6 out of 7. Aside from 6/7, the marks out of 7 decrease in a predictable frequency. 67 students (19.3%) got 5 out of 7 matches correct, 40 students (10.1%) got 4, and so on.

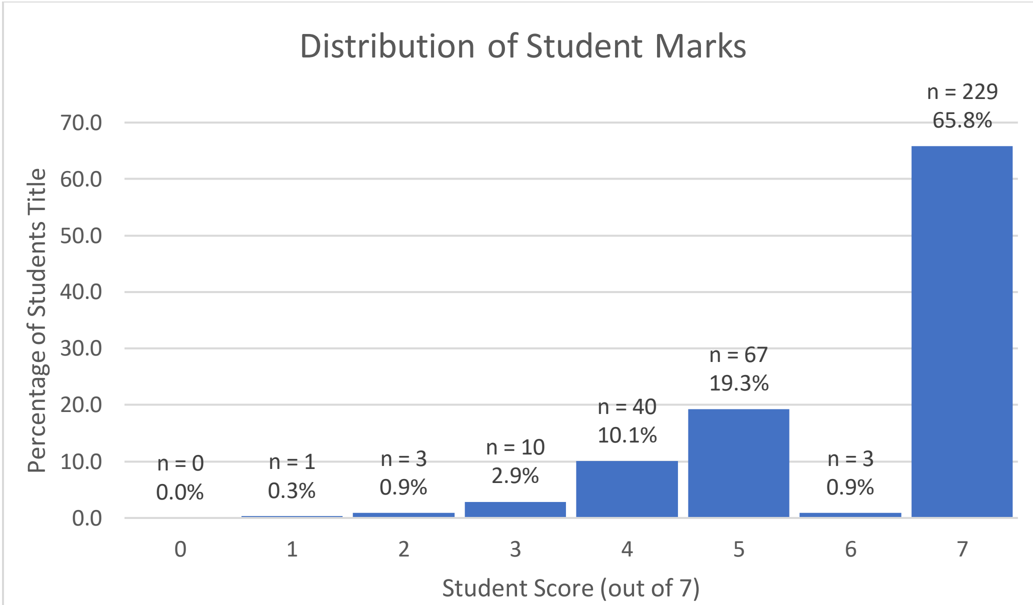

Figure 4. Number and percentage of students which achieved correct responses in a matching question related to the Salt VFE.

6.13 Geoscience Thinking Short-answer Question Data

In addition to the quantitative data obtained from the matching question, qualitative results were retrieved from students' responses to the two short answer questions, regarding geoscience thinking. Figure 5 shows the compiled responses of the 359 students who responded to the question "After having viewed this VR Tour, 'Salt' do you feel as if you've gained a greater understanding of what it means to think like a geoscientist? If so, please describe how this new Tour improved your spatial, temporal, system and/or field thinking". The raw data used to create Figure 5 is found in Table 11 in Appendix A. Due to the open-ended nature of this question, several student answers were unique. However, each written response was read and categorised to connect geoscience thinking after viewing the Salt tour. This was done by considering the overall themes of each student's response in the context of the definitions for each of the four ways of thinking established in Earth 121. Three of the four ways of thinking were subdivided into two additional categories. Therefore, the analysis contains a total distribution of nine potential categories in which student responses were divided. The nine categories are listed below, along with the way of geoscience thinking they most relate to in parentheses:

1. Improved understanding of scale and location of processes (spatial thinking)
2. Improved understanding of scale and location of deposits (spatial thinking)
3. What the law of Superposition is (temporal thinking)
4. How modern and ancient analogues contextualise the length of time processes take (temporal thinking)
5. How so many different environmental processes collaborate to form salt (systems thinking)
6. Better understanding of how field interpretations are made because of 2D image/text overlays (field thinking)
7. Improved sense of immersion and understanding of how geoscientists interact with the field (field thinking)
8. No improvement
9. Answer unclear

The distribution of student responses which correlated to each of the nine categories above are shown in Figure 5. 150 students (24%) described experiencing improvements to their temporal thinking, represented by the orange pieces of the pie graph. 118 of these students (19%) specified their improvements were facilitated by the modern and ancient analogues of salt, and how this contextualised the length of time salt formation processes take. The other 32 students

(5%) described improvements related to the law of Superposition, gaining a better sense of relative ages of stratified rock units. Systems thinking was one such category not subdivided, as the 144 students (23%) which reported improvements related to systems thinking all referenced a better understanding of the different processes and environments that work together to contribute to the formation of salt. Improvements to field thinking were reported by 143 students (23%). This type of thinking was further divided into 2 categories – students' ability to geologically interpret an environment, based on the design elements of the virtual tour, and students' ability to feel more immersed and understand how geoscientists interact with geologic environments. The majority of these students (113, 18%) noted improvements to feeling immersed and able to better understand environmental interaction, while 30 students (5%) expressed field thinking improvement related to the design elements. The light and dark blue pie pieces represent students that reported increases in their spatial thinking, for a combined total of 128 students, or 21%. Most of these spatially improved students (92 students, 15%) noted they gained a better understanding of the dimensions of the physical environments, referencing the size, shape, and location of the stratified salt deposits, while the other 6% (36 students) reported spatially-related improvements to their understanding of the dimensions of the processes that contribute to the formation of salt. The two separated, grey slices of the pie graph represent students that provided "no" (2.8% or 10 students) or unclear (12.5% or 45 students) responses to the question.

The analysis of written student responses, shown in Figure 5 allowed us to visually compare between the students that did experience improvements to their geoscience thinking, and those that did not (or were unclear). In fact, it is clear that, not only did a majority of students experience improvements to their thinking (91%), but each section of thinking (temporal, spatial, system, field) is larger than the no/unclear response sections (9%). Many of the students who answered no and provided an explanation as to why they answered no, explained that they did not learn new information to help them develop their geoscience thinking, presuming they already had it. Alternatively, students who provided unclear answers frequently provided either a response to a different type of question or a summary of their thoughts, potentially representing a lack of interest or attention.

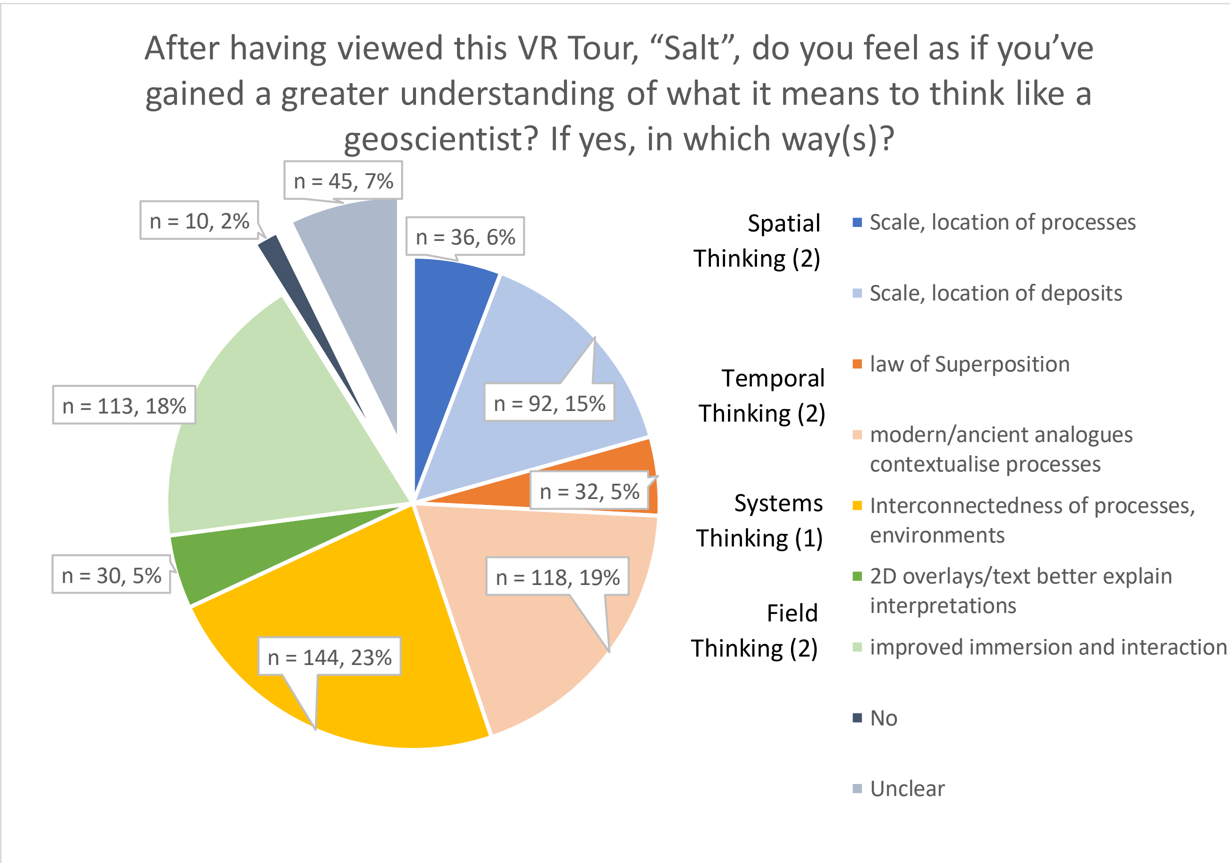

Figure 5. Pie graph showing the relative proportion of student responses when asked if the Salt virtual Tour helped them think like a geoscientist. There are five colours used and two shades of each to visually categorise student responses. The dark and light black slices (extending outward from the pie) represent answers of "No" and unclear answers respectively. Each of the other colours represent responses in any of the four ways of thinking that comprise geoscience thinking as a whole.

In order to better visualise the distribution of responses that weren't either "no" or unclear, it is clear from Figure 6 that the distribution was fairly even. Figure 6 provides a representation of the relatively equal distribution of reported improvements by students as a bar graph, rather than a pie graph. The raw data used to create Figure 6 is found in Table 12 in Appendix A. After having excluded those students who either answered "No" or responded unclearly about their geoscience thinking, students perceived increases to each of each of the four categories of thinking in similar proportions. The least student perceived way of geoscience thinking was spatial thinking at 42.3% while the most was temporal thinking at 49.3%. This is likely a result of the VFE design. The Salt VFE was created in such a way to facilitate the development of each of the four ways of thinking (temporal, spatial, system, field). A similar distribution of improvements reported by students suggests that the specific design choices were effective for each of the four ways of thinking. This implies that VFEs can be used to facilitate improvements in any or all of the ways of thinking, if designed with this intention in mind. Because students, in similar proportions, reported improvements to each of the four ways of thinking, associated with thinking like a geoscientist, the implementation of an intentional VFE helped students achieve Earth 121 foundational objectives.

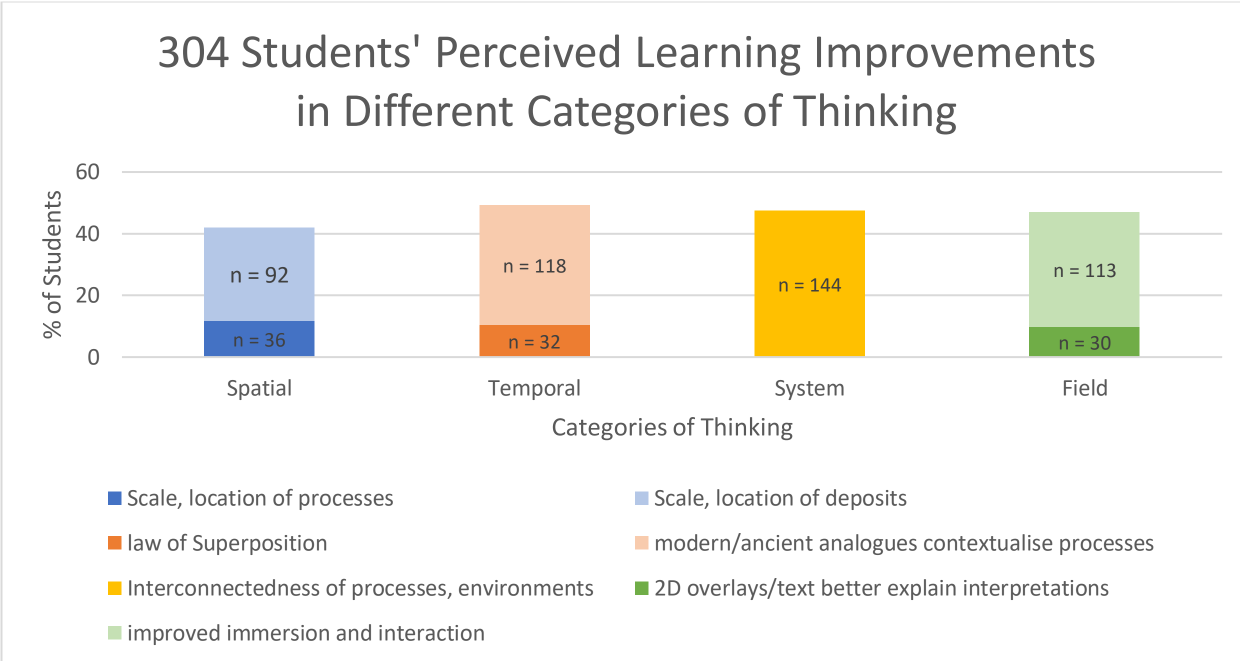

Figure 6. A plot of percentage of students who were able to think like geoscientists after having viewed the Salt VFE. Student written responses are categorised into one of the four ways of thinking and further subdivided, all related to thinking like a geoscientist. This plot is similar to Figure 5 but omits "no" and unclear responses.

6.14 Moments of Insight Short-answer Question Data

In addition to the distribution of student ways of geoscience thinking, students were also surveyed about any moments of insight/understanding/comprehension they experienced when viewing the Salt VFE. When it comes to experiencing moments of insight, 64 students (18%) were unclear in their response. 29 students (8%) stated that they did not experience any such moment while viewing the quiz. Of those that did, 61 (17%) expressed realisations related to the interconnected processes that form salt deposits. 68 students (19%) reported moments of insight related to depth and scale of the Goderich mine, and the stratigraphic units in which the mine is located. Students were particularly surprised to learn the comparison between the mine depth and the CN tower height. Still a sizable proportion, 48 students (13%) specifically mentioned gaining a better understanding of how an underground mine operates to extract salt. 32 students (9%) each reported moments of sudden insight related to the application of the law of Superposition and the uses for salt. Many were surprised to make the connection between everyday products that contain/use salt and the lithified strata containing halite hidden underground. 20 students (5%) better understood how Great Salt Lake has formed because of environmental and geologic conditions, and only 8 students (2%) explained they experienced a sudden moment of comprehension related to the transport and processing of salt. This data is from Table 13 in Appendix A and is used to create Figure 7 below.

The most commonly reported moments of insight/comprehension were related to the Goderich mine (13% operation, 19% size and scale) and to formative processes (17% evaporite deposits, 9% for Great Salt Lake). These may be the most common because of the visual immersivity of the Salt VFE. Many concepts do not necessarily require a visual component to be reasonably explained (such as the anthropogenic uses of salt), so it is more likely students would have already developed this knowledge. However, when it comes to concepts related to specific locations or environments, students may be experiencing this type of information for the first time. Specifically, many students have not had the opportunity to visit Great Salt Lake or the Goderich Salt Mine, so learning about these new places with visual capabilities of a VFE are more likely to illicit a new and enjoyable experience that leads to better motivation to learn, retention and overall understanding.

29 students (8%) reported not having experienced a moment of realisation, many of them explaining that the VFE did not help them learn anything they weren't already, at least slightly familiar with. A greater number (64, 18%) provided an unclear response to the question. Many of students discussed the content of the VFE but did not specify whether or not it provided a

moment of insight or comprehension. To reduce this confusion in the future, it is recommended students be provided with an option to select either yes or no and asked to elaborate on their selection.

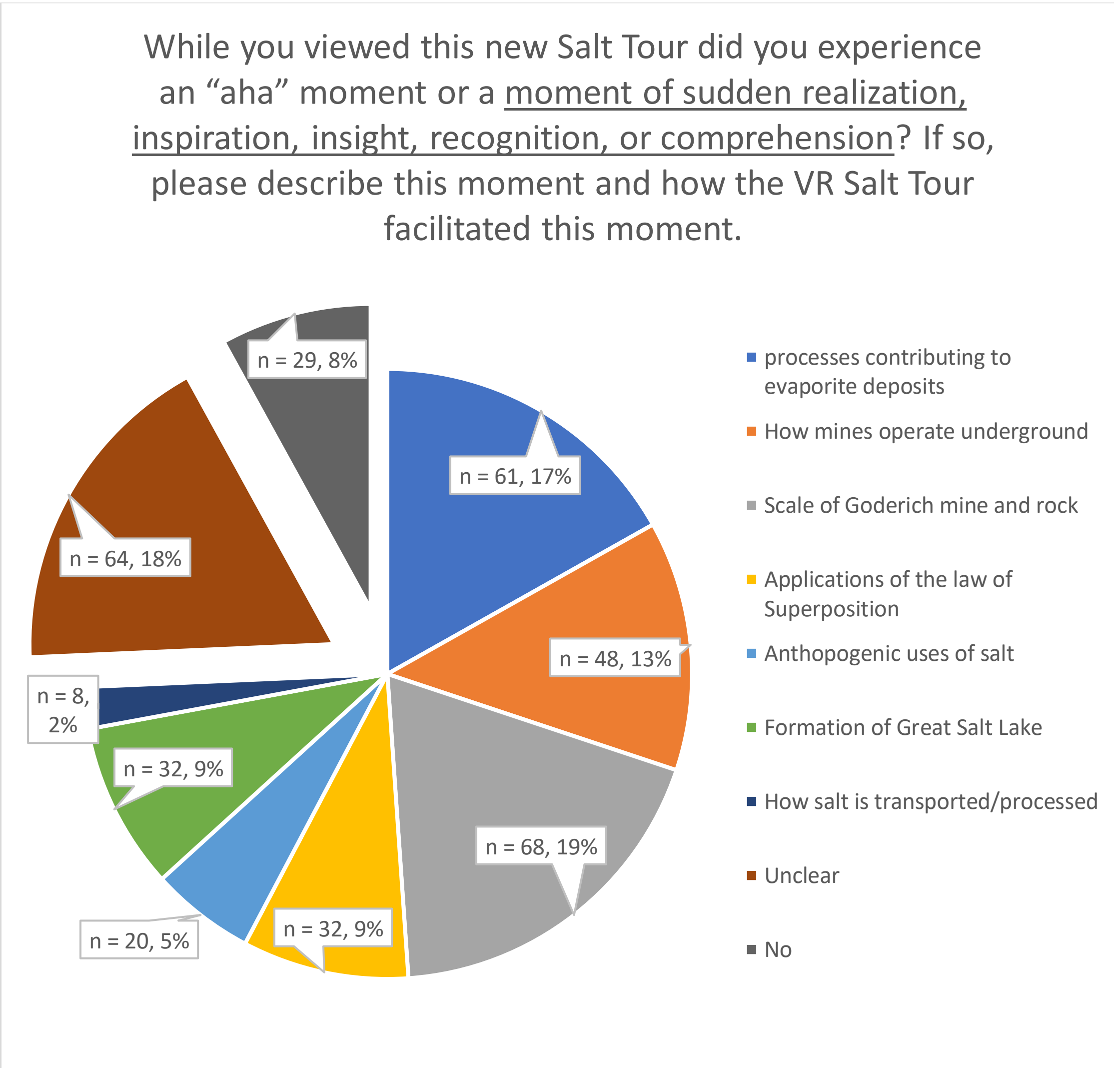

Figure 7. A pie chart showing the proportion of students who responded to a question about experiencing a sudden moment of insight while viewing the Salt virtual Tour. The recessed brown and grey slices represented students who either did not experience a moment of insight or were unclear in their response. The remaining slices represent students who provided responses that were similar, thematically. While many of these categories relate to the four ways of thinking, they are shown individually.

6.2 Earth 231 Mineralogy

6.21 Geologic Mapping Assignment Rubric Quantitative Data

The data collected and analysed from Earth 231 was based on student performance in each of the sections of the assignment rubric, as marked by Dr. Parks. Figures 8 and 9 provide a visual representation of the comparison of different groups of students from 2019 and 2020 in the form of boxplots. The raw data used to create Figure 8 is found in Table 14 in Appendix B. Figure 9 has been produced using the raw data from Tables 15 and 16 in Appendix B. For all boxplots, the X within each boxplot represents the mean grade value. The small circles represent the number of values. The horizontal line in each box is the median mark and the lines which extend vertical from some of the boxes represents the range of values. All statistical parameters shown in Figures 8 and 9 were calculated using Microsoft Excel and are summarised in Table 7 and 8.

It is important to note that, while there were four outcrops used in the 2019 term, only three were used in the 2020 term. To account for this difference, when comparing data by year and by outcrop, the fourth outcrop not used in 2020 was omitted. While we can make general observations from Figure 8 about the relative similarity in marks, the mean, and the number of groups that belong to each box, Table 7 provides a more detailed summary of this information. The first thing to note is that the marks in each set of years within each of the four groups are statistically similar, as seen by the t test result (Table 7). This means that the variation in marks between the 2019 class and 2020 class is small enough to be considered random, and not a result of external influences. Each of the four datasets from Table 7 are statistically similar because the absolute value of the test Statistic (t Stat) is less than the t Critical two-tail value. If two populations are statistically similar, it means that the difference between the marks in two populations is not significant. In other words, the variation is small enough that a difference in marks between the populations can be attributed to chance. In the event that the difference between two populations was statistically significant, it would suggest that the variation would be too great to be attributable to chance, implying the existence of other influences. Table 7 also provides the mean marks for each group, which are all similar between years (<4% increase) except for the carbonatite groups, which saw an average mark increase of almost 7%. While this may seem like a lot, as the t Stat results in Table 7 show, there is no reason to believe this increase was for any specific reason or influence.

While both the average and median mark for each group improved in 2020, because the populations in each of the four sets are statistically similar, we cannot say this improvement is attributable to anything other than randomness. Therefore, statistically, there was no significant change in overall marks. This is interpreted to mean that the VFE did not positively or negatively impact students' ability to successfully achieve the intended learning outcomes of the assignment.

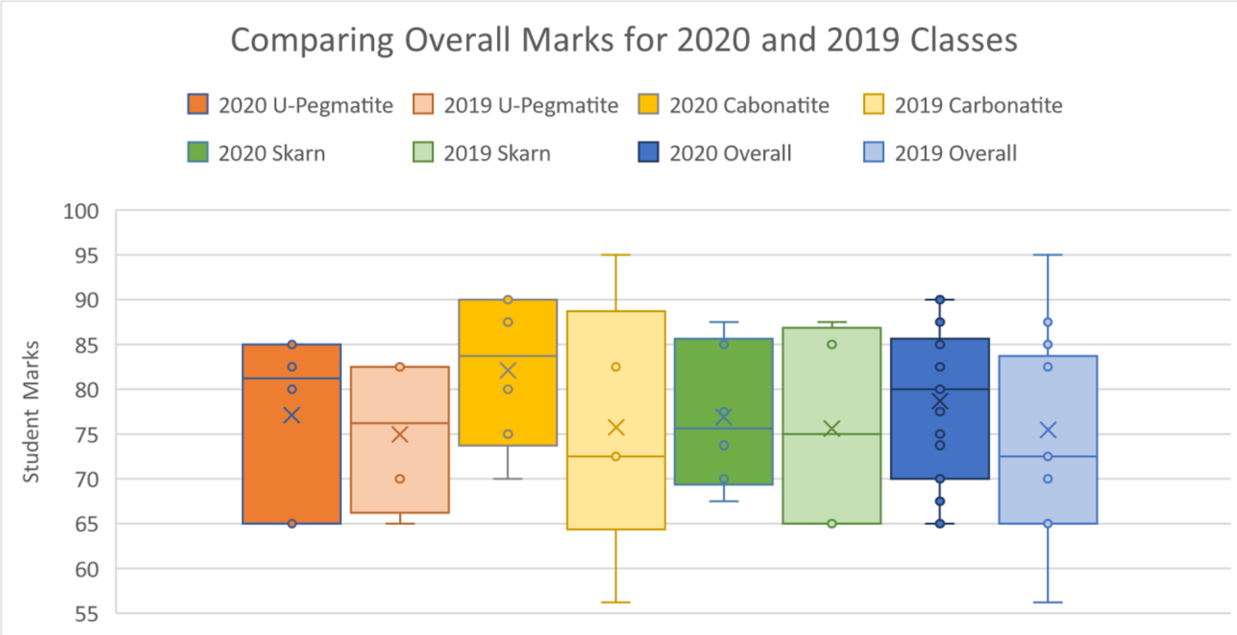

Figure 8. Boxplots comparing student grades from 2019 and 2020, taking into consideration all rubric marks as a whole. Each of the four colours corresponds to a different group of students, based on the outcrop they were responsible for (as well as the entire class as a whole).

Table 7. A chart comparing the quantitative information from each of the three outcrop groups, and the overall class. Each of the four groups contains two mean, variance, and observation datasets (one for each year) and one set of test Stats, P values, and t values.

	U-Pegmatite		Carbonatite		Skarn		Overall	
	2020	2019	2020	2019	2020	2019	2020	2019
Mean	77.08	75.00	82.08	75.75	76.88	75.63	78.68	75.48
Variance	91.04	79.17	71.04	204.38	64.84	151.56	72.88	125.92
Observations	6.00	4.00	6.00	5.00	6.00	4.00	18.00	13.00
Df	7.00		6.00		5.00		21.00	
t Stat	0.35		0.87		0.18		0.86	
P(T<=t) one-tail	0.37		0.21		0.43		0.20	
t Critical one-tail	1.89		1.94		2.02		1.72	
P(T<=t) two-tail	0.73		0.42		0.86		0.40	
t Critical two-tail	2.36		2.45		2.57		2.08	

Figure 9 provides a similar visual representation as Figure 8. Each of the boxplots provides some general information about how students performed in specific categories of the overall rubric, focusing on the rubric categories that could be impacted the most by the implementation of a VFE (see Table 6 above). By analysing the specific rubric categories discussed in Table 6, the impact (or lack thereof) of the use of a VFE can be quantified, via a statistically significant difference in marks. See Figure 11 for a more detailed analysis about student performance in each rubric criterion. Table 8, like Table 7, provides valuable information about the statistical relationships, averages, variances, and observations of student marks in 2019 and in 2020. T tests were used again to evaluate the statistical relationships between the two datasets. Table 8 shows that the 2019 and 2020 Map Element student marks are the only populations which are not statistically similar, as the absolute value of that t Stat of these two populations is greater than the t Critical two-tail value. The Map Elements rubric category refers to correctly including all of the typical scales and symbols necessary when creating a map. This means that the difference in marks in the Map Elements section is too large to be attributed to randomness. Conceptually, students' increased performance in their ability to correctly create the map elements associated with their map must be the result of a specific influence. Map Elements was the only rubric section with statistically significant change, each other section remained the same between years.

This change in marks could possibly be due to the following two reasons. Firstly, the course instructor may have unintentionally been more lenient when marking the Map Elements section as compared to previous years. This seems unlikely, given that this bias is not also seen reflected in an improvement in overall marks from year to year, or any of the other marks from the other rubric sections. Another potential reason for the increase may be a result of students being better at creating the Map Elements of their project in 2020 compared to 2019. This is a more probable reason because of the online restructuring of the mapping assignment. Students participated in a lab in 2020 in which they learnt specifically about creating Map Elements, and were able to practise this, and receive instructor feedback. This was something students had not done in previous terms and may be the reason why students performed better in the Map Elements section of the rubric in 2020. The students had more practice and knowledge than previous year's classes, because of the lab. This is not directly attributable to the VFE itself, but indirectly, the implementation of the VFE created an opportunity for students to practise their map elements more, thus resulting in a higher mark.

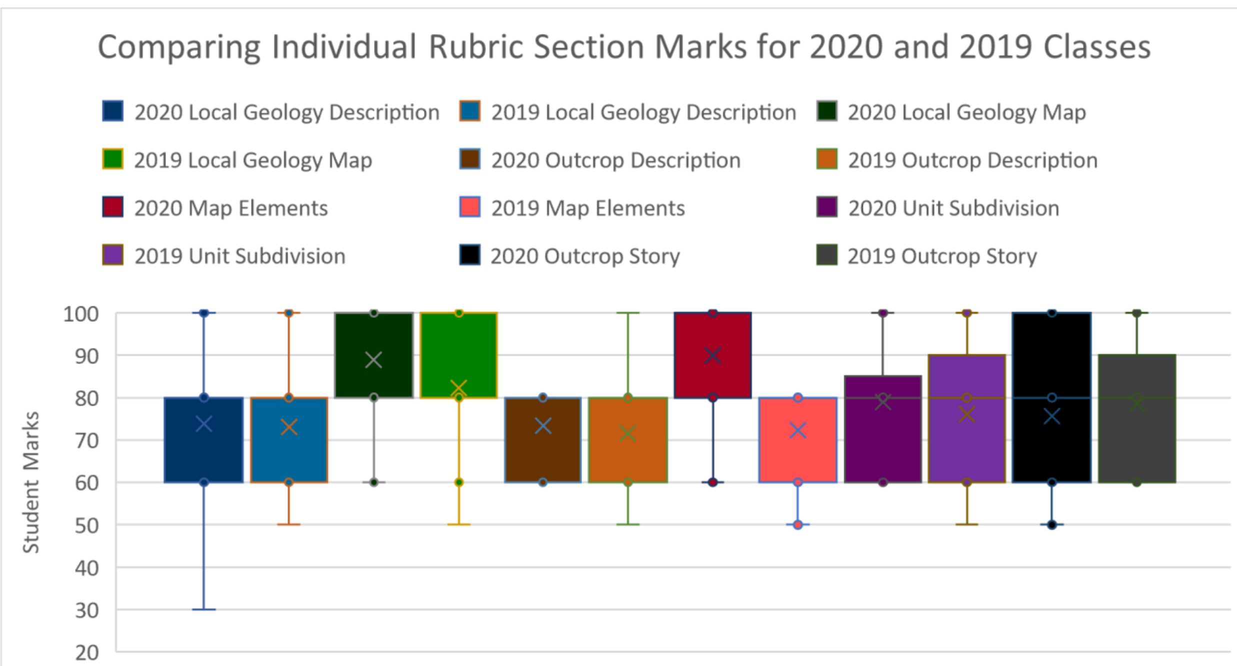

Figure 9: Boxplots representing overall student performance (no division based on outcrop) for 2019 and 2020, for each section of the rubric determined to be potentially affected by the changes associated with making the assignment fully virtual. Each of the seven sets of colours represents one section of the rubric.

Table 8: a chart comparing the quantitative information from each of the seven rubric categories. Each of the seven groups contains two mean, variance, and observation datasets (one for each year) and one set of test Stats, P values, and t values.

	Local Geology Description		Local Geology Map		Outcrop Description		Map Elements		Unit Subdivision		Outcrop Story	
	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019
Mean	73.89	73.08	88.89	82.31	73.33	71.54	90.00	72.31	78.89	76.15	75.56	78.46
Variance	272.22	256.41	198.69	235.90	94.12	197.44	200.00	152.56	210.46	292.31	343.79	230.77
Observations	18.00	13.00	18.00	13.00	18.00	13.00	18.00	13.00	18.00	13.00	18.00	13.00
df	26.00		25.00		20.00		28.00		23.00		28.00	
t Stat	0.14		1.22		0.40		3.70		0.47		-0.48	
P(T<=t) one-tail	0.45		0.12		0.35		0.00		0.32		0.32	
t Critical one-tail	1.71		1.71		1.72		1.70		1.71		1.70	
P(T<=t) two-tail	0.89		0.23		0.70		0.00		0.64		0.64	
t Critical two-tail	2.06		2.06		2.09		2.05		2.07		2.05	

7.0 Summary and Discussion

This thesis was established as a result of the educational benefits identified by other experts in previously conducted studies involving VFEs (primarily, the capacity for VFEs to both engage students and contribute to their development of geoscience knowledge) and a successful, funded opportunity. Having received a grant to explore this emerging technology, UW-EES initially assessed that, based on the potential benefits of VFEs (summarised in the Literature Review section), integrating VFEs into undergraduate geoscience education would at least serve as a valuable proof-of-concept to UW-EES, if implemented correctly. Being able to conclude that VFEs are useful or not useful within UW-EES was viewed as a valuable pursuit in and of itself. In order to determine whether or not students could use this technology to better develop their geoscience knowledge and achieve course learning objectives, it was important to design and introduce VFEs in a way that would facilitate these goals. As noted by the findings of other experts, this thesis concurs that, when effective geoscience pedagogy is used to design VFEs, students are able to develop their thinking skills and geoscience knowledge (more specifically, in the context of the four ways of thinking like a geoscientist). Another finding with which this thesis agrees is that VFEs can be customised to effectively target existing geoscience learning outcomes. Therefore, VFEs can be effective in situations where course assessments are designed with them and in situations where VFEs are used to modify existing assessments.

In Earth 121, an effective strategy for facilitating geoscience thinking was designing in each Scene of the VFE around a specific geoscience-related objective. This was helpful for ensuring the information in a Scene wasn't extraneous and therefore unhelpful or distracting to students. Another strategy was editing 2D images before using them as POIs in each Scene, to ensure the images complemented student learning. Overlaying the Goderich mine shaft on a cross section of the regional stratigraphy for example helped students better understand the shape and depth of the mine. Using the final Scene in the VFE as a summary was effective for helping students connect each of the previous Scenes and concepts together, comprehensively in one place. In terms of software, Google Tour Creator was selected as it was a free and easy-to-use option for creating 360-degree VR VFEs. Google Tour Creator also had built-in compatibility with Google Street View, allowing VFE creators to select 360-degree photospheres from any existing location in Google Street View. Once created, the VFE is hosted on Google's Poly website – a repository of all VFEs created with Google Tour Creator. It is worth noting that Google will be discontinuing this software as of June 30th, 2021. The same style of VFE however, can be created using other available virtual tour software. The easy ability to customise VFEs suggests that, of the many virtual tour software that exist, effective geoscience pedagogy can still be used to design VFEs that facilitate a fascinating new avenue for student learning. One advantage, unique to Google Tour Creator is the ability to use photospheres from Google Street View as VFE Scenes, making it easy to create Scenes with interesting, high-quality, geologically significant 360-degree photospheres from all over the world. Other virtual tour software do not have this feature, meaning VFE Scenes have to be 360-degree photospheres photographed and uploaded by the creator, something that may cause a barrier or limit which locations are used.

In Earth 231, a new VFE was created for an already-existing course assignment used in previous terms during a field trip to achieve similar outcomes. In times when travel options are limited, VFEs can be implemented to still allow students to achieve existing assignment learning objectives. Field experiences however remain much more immersive and offer opportunities to develop unique skills and therefore cannot be replaced by VFEs. For Earth 231, high resolution panoramic images of outcrops (containing POIs with text) and videos performing HCl tests were sufficient for students to map and interpret outcrops in Bancroft, Ontario. This was done by uploading panoramic images of geologic outcrops (captured with a 360-degree camera, in-person) to the Gigamacro website. Gigamacro allows users to add (and viewers to select) text-based POIs anywhere on the panoramic image. The POIs contained text about diagnostic properties of the rock at the location of the POI that would otherwise need to be tested in-person (such as mineral hardness). In order to guide students to important areas or features of the outcrop, a series of about 20 2D images were included for each outcrop. While these images did not show the entire outcrop (like the panorama), they provided detailed, close-up photographs which helped students improve their observation skills and analyse specific areas of the outcrop. A short video file was also provided, demonstrating an HCl test on rock samples from the outcrop, as this diagnostic test is best observed over a short amount of time, not in an instant (which could otherwise be captured by a static image).

This thesis concludes that VFEs are effective and worth utilising in undergraduate geoscience courses. Not only can they facilitate geoscience learning, but they are highly adaptable. Earth 121 students specifically reported that the 360-degree VR VFE was an interesting an engaging way of learning. Due to the discontinuation of the software used to create the Earth 121 VFE, new virtual tour software options will have to be explored, in order to find a suitable alternative for creating this type of VFE. In order for VFEs to be effective, they must be carefully and intentionally designed to align with intended learning outcomes, best practices in VFE and assessments, which may require a significant time commitment and geoscience knowledge. While Earth 231 students were able to achieve statistically similar grades using a VFE compared to a field trip, this does not suggest that VFEs can be used as a replacement to field trips. In fact, previous research has unanimously concluded that VFEs are not as comprehensive as field trips for the development of field-based skills, knowledge, and experience. However, VFEs can be used to help students achieve very specific outcomes, in the event field trips are not feasible. And most importantly, VFEs can best help prepare students for field trips, familiarising them with the complexities and dynamic nature of immersing oneself in the Earth system.

8.0 Conclusions

- Students in Earth 121 successfully applied geoscience knowledge learnt from the Salt VFE, as shown from the quantitative matching question results. These results may have been influenced by the structure of the matching question and available responses. Students reported overwhelmingly being able to think like geoscientists, relatively evenly in each of the four ways of thinking, suggesting VFEs can be intentionally designed to facilitate geoscience thinking and specifically four ways of geoscience thinking. Students experienced moments of insight mostly related to locations or processes they would have otherwise not experienced in person (the Great Salt Lake and underground Goderich Mine).
- Students in Earth 231 earned similar overall grades between a field assignment in 2019 compared to a remote assignment in 2020 (due to the pandemic). Although this supports a good alternative when field work cannot be completed, remote analysis does not replace the value of field work. Significantly higher marks were earned by students for one specific section of the assignment - the formatting and creation of their map elements (legend, symbols, scale). This may be related to an added lab exercise in 2020 where students were able to practise and receive feedback on creating map elements.
- VFEs are an emerging technology that is both engaging for students and able to be intelligently designed to facilitate learning. It is critical that VFEs are designed in such a way to integrate course learning objectives, in order to be effective. Good pedagogy is imperative to facilitate student learning and VFEs as a technology to support this are no exception.

9.0 Recommendations

- In Earth 121, the matching question could be improved by adding text descriptions that are more comprehensive and potentially used in multiple responses.
- In Earth 121 the written questions asking students to describe moments of insight/comprehension/understanding could be improved by redesigning the questions to allow for students to check Yes or No first, and then ask for an explanation. This will reduce the number of unclear responses, as the person coding/categorising will not need to decide a “yes” or “no” based upon written answers.
- Regarding Earth 231, it is recommended that students continue to receive practice creating map elements, prior to the group term project. It is clear that this was beneficial to students’ abilities to properly include and format the different map elements. Additionally, lessons involving other rubric sections could be incorporated into labs before the term project, to test whether students can improve on the assignment more than in just one section (map elements).
- VFES should be created in line with specific course objectives in order to ensure they are effective.
- More VFEs should be created for introductory undergraduate geoscience courses. VFEs should also be further explored in settings where instructors are able to guide students through them, in order to compare the effectiveness of students guiding themselves and teacher guided VFEs.
- An alternative virtual Tour software should be sought, due to the upcoming discontinuation of Google Tour Creator and Google Poly.

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Appendix A: Earth 121

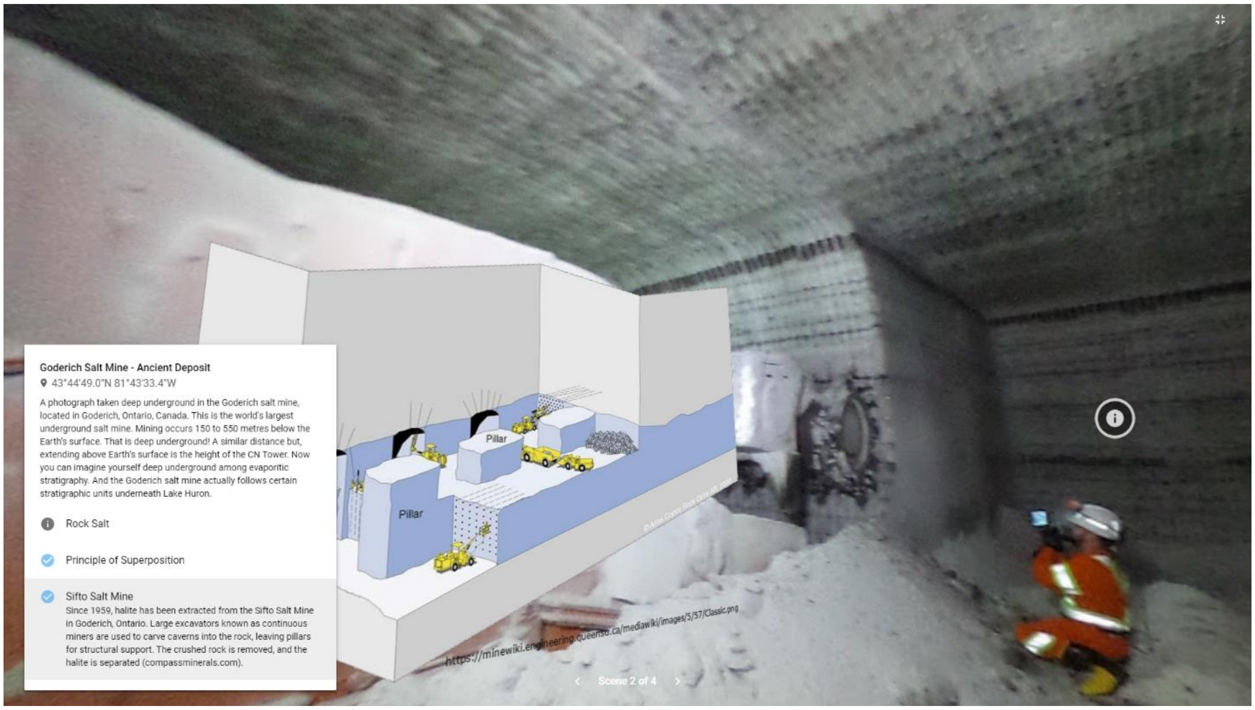


Figure 10: Scene 2 from the Salt VFE containing POI marker (right "i" icon), POI 2D image (centre excavator and cavern diagram), and POI text (left text box).

Question 1: Knowledge-Based Matching Question

Table 9. Earth 121 question 1 data regarding frequency and number of students which selected the two most common responses for each definition.

	Correct Response Frequency (%)	Number of Students	Most Common Wrong Response Frequency (%)	Number of Students
Modern environment where salt forms.	85.3	297	12.4	38
Largest salt mine	97.1	338	2.3	2
Common mineral found in rock salt.	81.6	284	13.2	40
Salt formation period	99.1	345	0.3	1
Nonmetallic mineral resource	71.0	247	11.8	46
Stratigraphic principle used to determine relative age of salt layers.	99.4	346	0.3	1
Rock Salt rock type	84.2	293	11.5	41

Table 10. Distribution by percent and count of question 1 student scores out of 7.

Student Score (out of 7)	Percentage of Students	Number of students
0	0.0	0
1	0.3	1
2	0.9	3
3	2.9	10
4	10.1	35
5	19.3	67
6	0.9	3
7	65.8	229

Question 3: Categories of Thinking Like a Geoscientist

Table 11. Distribution by percent and count of question 3 codified student responses about categories of geoscience thinking (including No and unclear responses).

Category of Thinking	Category Subdivisions	Percentage of Students	Number of Students
Spatial	Scale, location of processes	10.0	36
	Scale, location of deposits	25.6	92
Temporal	law of Superposition	8.9	32
	modern/ancient analogues contextualise processes	32.9	118
Systems	Interconnectedness of processes, environments	40.1	144
Field	2D overlays/text better explain interpretations	8.4	30
	improved immersion and interaction	31.5	113
None	No	2.8	10
	Unclear	12.5	45

Table 12. Distribution by percent and count of question 3 codified student responses about categories of geoscience thinking (excluding No and unclear responses.

Category of Thinking	Category Subdivisions	Percentage of Students	Number of Students
Spatial	Scale, location of processes	12	36
	Scale, location of deposits	30.26316	92
Temporal	law of Superposition	10.52632	32
	modern/ancient analogues contextualise processes	38.81579	118
Systems	Interconnectedness of processes, environments	47.36842	144
Field	2D overlays/text better explain interpretations	9.868421	30
	improved immersion and interaction	37.17105	113

Question 4: “Aha” Moments

Table 13. Distribution by percent and count of question 4 codified student responses about “Aha” moments (including No and unclear responses.

Category of "Aha" Moment	Percentage of Students	Number of Students
processes contributing to evaporite deposits	17.0	61
How mines operate underground	13.4	48
Scale of Goderich mine and rock	18.9	68
Applications of the law of Superposition	8.9	32
Anthropogenic uses of salt	5.6	20
Formation of Great Salt Lake	8.9	32
How salt is transported/processed	2.2	8
Unclear	17.8	64
No	8.1	29

Appendix B: Earth 231

Fall 2020 Assignment Outline

Earth 231
Final Group Assignment
This is not online lab 4, please make sure to check that for this week's deliverables!!
Presentation dates: Dec 1, 2 and 3, depending on lab session
Paper due date: Dec. 7th at 4:30 pm
Paper submission: Digital copy of text uploaded to dropbox on LEARN

Now it's time for your group to write a longer, more detailed geological report and prepare a short presentation on your topic. Your paper is due a few days after your presentation so you can add or modify your paper based on any insight you might gain from discussion during your presentation.

OBJECTIVES: The aim of the written report is to prepare a geological report describing your topic and outcrop. The aim of the presentation is to provide a brief overview of your topic and the geology of your outcrop, and its geological history to the rest of the class.

PRESENTATION DETAILS:
You have 10 minutes (max!!) to present your information to the class, followed by ~3-5 minutes for questions and discussion. You can prepare a PowerPoint or use whatever method you'd like to deliver the information to the class. You must include:

1. information about your topic,
2. the geological map you've made of your outcrop and the units you have defined, and
3. an interpretation as to how your outcropped formed. You will do this by interpreting the map you made, but also keeping in mind about what you now about how the rocks that are related to your topic formed.

Besides that it is really up to you what you present.

PAPER SUBMISSIONS
We will be using Turnitin. To submit your paper, your group must upload into the dropbox "Group Projects FINAL Submission FOR GRADING" on LEARN. You must submit your paper in PDF format (not MS Word or other word processing formats). More information on Turnitin and how it will use it in this course can be found at the end of this handout.

PAPER DETAILS:
Write a geological report describing your field site. Make sure to include the following:

1) Mandatory cover sheet/title page - will be posted on LEARN
2) Abstract (1 page)
3) Main body (text, ***exclusive*** of maps & figures) ~8 pages, 1.25 to 1.5 spaced, Times New Roman, Cambria or Arial size 10 font), including:
    a. Section 1: A short review and description of your topic rocks and how they form.
    b. Section 2: Regional Geology:
        i. A description of the Grenville province. Discuss the different subdivisions (i.e. belts or terranes) of the Grenville and make sure to indicate what part of the Grenville you site is located in
        ii. A geological map showing the Grenville Province and any further subdivisions you feel are important. Once again make sure to indicate what part of the Grenville province your site is located in.
    c. Section 3: Local Geology
        i. Section 3a) a description of the rocks AROUND (not at) your outcrop
            1. Take a look at the map you handed in in online lab 2, and discuss the local context in which your site/rocks occur
            2. Include a corrected/updated version of the geological map you handed in as part of online lab 2
        ii. Section 3b) a description of the rocks AT your outcrop
            1. A description of what you observed at your outcrop, including
                a. a concise description of each rock unit/type you show on your map. You DO NOT need to describe each individual picture of rocks we gave you on your outcrop, instead you need to group the photos/individual rocks into logical rock units that you show on your map. These units should be described in a logical order (either oldest to youngest, or from one side of your outcrop to the other e.g. east to west, etc)

b. a description of the spatial/age relationships between the different rocks, based on the cross cutting relationships you observed in the outcrop and field photos. *Use lots of photos to prove to your points/show important contact relationships*

2. A detailed geological map of your outcrop. Remember that this is a real map, and must include elements included on all maps (north/directional arrow, co-ordinates, scale, legend with symbols, etc).

d. Section 5: Geological history
   i. How did the rocks at your site form? Make interpretations from the observation you made in the from observing and mapping your outcrop, in conjunction with current ideas you find in the geological literature about how your topic rocks formed. Make sure to show evidence of your group's own independent and critical thoughts.

e. Section 6: Conclusions
   i. Do not present any new ideas or information here!! Instead summaries the most important points you have made in your paper

4) References (see section below on references)

MARKING:
A copy of the rubric used last year will be made available on LEARN. I may make minor revisions/changes, but the bulk of the rubric will stay the same. It is possible that not all group members will receive the same mark on the project, as your final mark will be influenced by your peer evaluation. This will be discussed more in class.

NOTES ON REFERENCING AND COMMON ISSUES/PROBLEMS

The top three mistakes with referencing in my experience as an instructor are:

1. **Not citing ALL sources listed in your references list WITHIN the text**
2. **Not listing ALL references cited in the text in your reference list**
3. **Not including references in figure captions if you did not make the figure**
   - **Need to place an in-text reference in the figure caption. If you have modified anything (like the map in your first report) the reference should read *"(modified from author, year)"***

Use the style of referencing found in the Canadian Journal of Earth Sciences (APA style). Marks will be deducted for improper referencing. See "referencing format.pdf" on LEARN for format for the reference list at end of main paper. Below are samples of correct "in-text" references. If in doubt, please ask!!

- In text references:
  - One author:
    - (Parks, 2013)
  - Two authors:
    - (Parks and Lin, 2013)
  - Three or more authors:
    - (Parks et al, 2013)

Acceptable types of references include

1. Journal articles
2. Textbooks

No web references, unless it is a URL or DOI link to a published journal article This also means no online encyclopedias!!! Marks will be deducted. Use textbooks instead!!!

Using Turnitin in EARTH 231[1]

WHAT IS TURNITIN AND HOW WILL IT BE USED IN EARTH 231?
Turnitin is a text matching tool that works by comparing your written assignment with a database of millions of web pages, academic books and articles, as well as other students' papers. In EARTH 231 you will have the opportunity to use Turnitin yourself, in order to assess your draft version so that you can identify and then correct any problems before you submit your final version for grading.

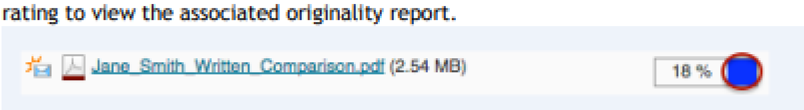
[1] Modified with permission from BIOL 273 course material

How will this work?
There are two dropbox folders on our LEARN site:

1. "Group Projects DRAFT Submission" dropbox.
2. "Group Projects FINAL Submission FOR GRADING" dropbox.

In the "Group Projects DRAFT Submission" dropbox you will be able to submit a draft version of your paper and see the Turnitin originality check results for it. You can then make changes to your draft and then submit your final paper to the ""Group Projects FINAL Submission FOR GRADING" dropbox.

WHEN SHOULD I SUBMIT MY DRAFT(S)?
I recommend that you submit your draft to the daft submission dropbox a few days before your paper is due. Once you submit your draft to the dropbox it might take some time (i.e., minutes, or in some cases even a day or more) to receive the Turnitin originality report. You'll need to give yourself time to interpret the report and then make any necessary adjustments to your paper before submitting your final written comparison.
How do I see the originality report?
You can view the originality report from the Folder Submissions page. Click the coloured section beside the percentage rating to view the associated originality report.



WHAT WILL I RECEIVE FROM TURNITIN?
Turitin highlights and colour-codes unoriginal content and produces an Originality Report that includes a similarity index (a percentage) indicating how much of the submission was not original. The originality report can help you identify where you might have unintentionally used poor paraphrasing when summarizing information from another source.
When the Originality Report is ready, you will see a percentage of the amount of matched (i.e., unoriginal) content. A lower percentage rating indicates that most of the content is original; a higher percentage rating indicates that much or all of the content matches content fund in other sources and require further investigation. The percentage ranges are associated with colours, as follows:
Blue: >= 0 and < 20%
Green: >= 20 and < 40%
Yellow: >= 40 and < 60%
Orange: >= 60 and < 80%
Red: >= 80 and <= 100%

HOW DO I INTERPRET THE ORIGINALITY REPORT?
The percentage itself only tells you how much of the paper is the same as other sources (i.e., how much of your content is not original): the higher the percentage, the more the assignment will require revisions. Note that there is no "safe" colour or percentage. Therefore, no percentage or colour in the originality report can fully evaluate whether text has been plagiarized. Rather than focusing solely on the percentage, go through your paper and look at the highlighted sections. Those are where some re-writing needs to be done.

In EARTH 231, and in Science in general, direct quotes are not acceptable so direct matches should be addressed before you submit your final version for grading. This means that you need to paraphrase correctly with citations in the APA style.
If you need help interpreting the originality report you can refer to the Turnitiin website http://turnitin.com/en_us/features/originalitycheck. Cumbria University also has a good video on how to interpret the Turnitin originality report:
http://www.cumbria.ac.uk/StudentLife/Learning/SkillsCumbria/DigitalLearning/Turnitin.aspx
If you need help with paraphrasing, you can seek help from the Writing Centre https://uwaterloo.ca/writing-centre/

Figure 11. 2020 Earth 231 mapping project outline and requirements

Fall 2020 Outcrop Resources

U-Bearing Pegmatite

You are mapping the outcrop on the west side of the road.
Location:
44°46'26.5"N 78°21'38.8"W, 4985 County 507 Rd, Gooderham, Ontario
Google street view:
U-bearing pegmatite: https://goo.gl/maps/4xnqzxieiVsiidLN7
High resolution panorama of the outcrop:
https://viewer.gigamacro.com/view/8esmMHQNnPVIYWGy?x1=22245.12&y1=-3767.42&res1=3.72&rot1=0.00
OGS map (from assignment #2)
https://viewer.gigamacro.com/view/AAMwRjGrKAIegYQk?x1=7028.50&y1=-430.90&res1=3.53&rot1=0.00

Carbonatite

You are mapping the outcrop on the north side of the road.
Location:
45°00'34.9"N 78°15'07.7"W, Essonville Line, Tory Hill, Ontario - Essonville Line
Google street view:
Carbonatite: https://goo.gl/maps/1Yek2JJrQWpufRNdA
High resolution panorama of the outcrop:
https://viewer.gigamacro.com/view/QjQVHGVpXaPWSE3k?x1=20551.63&y1=-4666.47&res1=21.42&rot1=0.00
OGS map (from assignment #2)
https://viewer.gigamacro.com/view/nfEqkCZgyK7tLruJ?x1=3992.67&y1=-1192.80&res1=5.88&rot1=0.00

Skarn

You are mapping the outcrop on the west side of the road.
Location:
44°54'57.4"N 78°04'38.4"W, 25738 ON - 28, Harcourt, Ontario - Dyno Road Skarn
Google street view:
Skarn: https://goo.gl/maps/YrqPQ5zHewwNdCaF6
High resolution panorama of the outcrop:
https://viewer.gigamacro.com/view/P8lUmf5agnZx8NUm?x1=18017.12&y1=-3197.11&res1=10.27&rot1=0.00
OGS map (from assignment #2)
https://viewer.gigamacro.com/view/AAMwRjGrKAIegYQk?x1=7028.50&y1=-430.90&res1=3.53&rot1=0.00

U-Bearing Pegmatite Outcrop Sample Resources

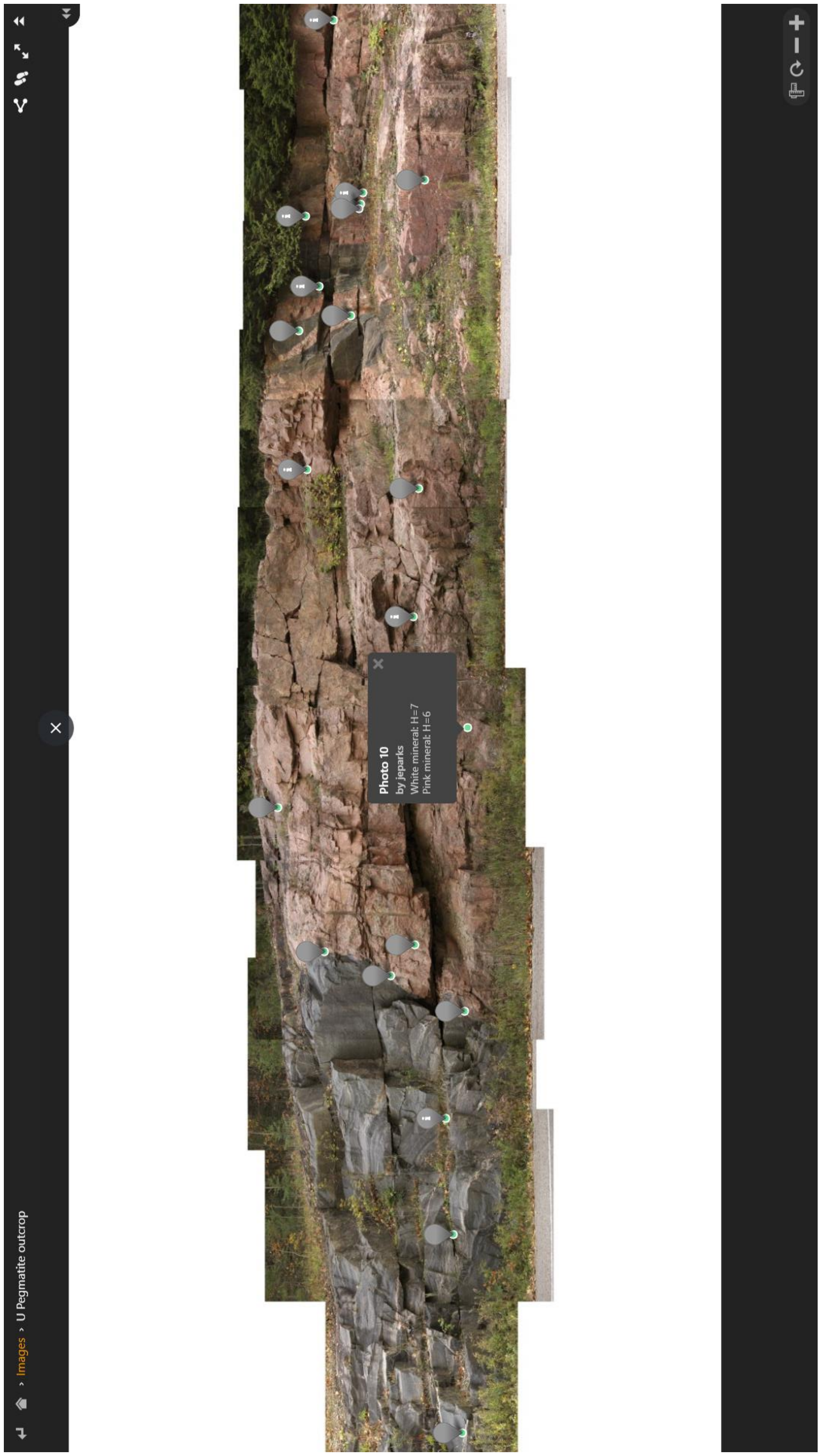


Figure 12. The panorama provided to the 2020 U-bearing pegmatite groups. The many grey location markers are the POIs.

Figure 13. One of about 20 close-up photos the 2020 U-bearing pegmatite group received to help interpret their outcrop. The remaining close-up pictures are in Learn.

2020 Group Marks

Table 14. Overall marks achieved by 2020 and 2019 classes, divided by outcrop.

	2020	2019
Outcrop group	Group Mark (%)	Group Mark (%)
U-Pegmatite 1	65	65
U-Pegmatite 2	82.5	70
U-Pegmatite 3	80	82.5
U-Pegmatite 4	65	82.5
U-Pegmatite 5	85	
U-Pegmatite 6	85	
Carbonatite 1	75	72.5
Carbonatite 2	90	56.25
Carbonatite 3	90	72.5
Carbonatite 4	70	82.5
Carbonatite 5	87.5	95
Carbonatite 6	80	
skarn 1	67.5	65
skarn 2	73.75	65
skarn 3	87.5	87.5
skarn 4	85	85
skarn 5	77.5	
skarn 6	70	

Table 15. Marks of the 2020 groups in the six rubric categories determined to be affected by the VFE.

2020						
Outcrop Group	Description (%)	Local map (%)	Description of rock units and outcrop (%)	Map elements (%)	Unit subdivision/accuracy (%)	Outcrop story (%)
1	60	80	60	80	60	60
2	100	100	60	100	60	60
3	60	80	80	60	80	50
4	80	60	80	80	80	100
5	80	100	80	80	100	100
6	30	100	80	100	80	60
7	80	80	80	100	100	60
8	100	100	80	80	80	100
9	60	80	80	100	100	100
10	80	100	60	60	60	50
11	80	100	60	80	60	60
12	80	80	80	100	100	80
13	80	100	80	100	80	80
14	60	100	80	100	80	100
15	80	100	60	100	60	80
16	80	100	80	100	80	80
17	80	60	80	100	80	80
18	60	80	60	100	80	60

2020 Rubric

Presentation	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Oral communicaiton skills/creativity	Excellent and/or very creative	Good and/or very creative	Adequate	Marginal	Very poor	/ 2.5
Outcrop map	Excellent	Good	Adequate	Marginal	Very poor	/ 2.5
Scientific content	Excellent	Good	Adequate	Marginal	Very poor	/ 2.5

Report format	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Format	Excellent, proper format	Good, proper format	Improper format	Improper format, one section missing	Improper format, many sections missing	/ 2.5
Writing style, spelling and grammer	Excellent, few or no errors	Good, some errors	Adequate, some or many errors	Marginal, many errors	Poor, many errors	/ 2.5

Referencing	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Type/appropriatness	Excellent, relevant sources	Good, relevant sources	Adequate, source could be better	Marginal, web references included	Poor, web references included	/ 2.5
Paraphrasing, use of in-text references	Excellent	Good	Adequate	Marginal	Poor	/ 2.5
Format	Excellent, proper in text references, all sources listed	Good, minor improper in text references and/or one source missing	Adequate, minor improper in text references and/or one source missing	Many improper in text references, and/or more than one source missing	Major issues with referencing	/ 2.5

Report	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2.5 points	Level 1 1.5 points	Criterion Score
Report: general persentation of data, depth and breadth	Data and interpretations presented in a logical manner, Superior grasp of subject matter	Data and interpretations presented in a logical manner, Reasonable grasp of subject matter	Data and interpretation mixed, Reasonable grasp of subject matter	Data not presented well, Some grasp of subject matter	Little to no grasp of subject matter	/ 5

Topic rocks	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2.5 points	Level 1 1.5 points	Criterion Score
Review and description of your topic rocks	Excellent description of topic rocks	Good description of topic rocks	Adequate description of topic rocks	Poor description of topic rocks	Inadequate or missing description of topic rocks	/ 5

Regional geology: Grenville	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Description of Grenville	Excellent description of the Grenville	Good description of the Grenville	Adequate description of the Grenville	Poor description of the Grenville	Inadequate description of the Grenville	/ 2.5
Map of Grenville	Excellent map, relevant and contains all required components	Good map, relevant and contains all required components	Adequate map, some what relevant and contains most required components	Poor map, is not relevant and does not contains all required components	Missing	/ 2.5

Local geology: around your outcrop	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Description	Excellent description of the local geology	Good description of the local geology	Adequate description of the local geology	Poor description of the local geology	Very poor description of the local geology	/ 2.5
Local map	Excellent map, contains all required components	Good map, contains all required components	Adequate map, contains most required components	Poor map, does not contains all required components	Very poor map, does not contains all required components	/ 2.5

Your outcrop	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2.5 points	Level 1 1.5 points	Criterion Score
Description of rock units and outcrop	All units identified and described logically, excellent age relationships	Most units identified and described logically. Good age relationships. Some minor details missing	Some units not identified or description is lacking. Adequate age relationships. Details are missing	Poor descriptions of different units. Poor age relationships	Unacceptable descriptions of units and/or missing significant units. Not enough detail provided	/ 5

Outcrop Map	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Map elements	excellent legend and symbols	good legend and symbols	adequate legend and symbols	Marginal legend and symbols, items missing	Unacceptable legend and symbols, many items missing	/ 2.5
Unit subdivision/accuracey	Excellent amount of detail, map is accurate	Good amount of detail, map is mostly accurate	Adequate amount of detail, map is inaccurate in places	Marginal amount of detail, important details are missing	Unacceptable amount of detail, many important details are missing	/ 2.5

Geological history	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2.5 points	Level 1 1.5 points	Criterion Score
The story from your outcrop	Excellent, well thought out. Reasonable analysis	Good, well thought out. Reasonable analysis	Adequate, some aspects not well thought out, or details missing. Adequate analysis	Marginal, many aspects not well thought out, or many details missing. Weak analysis	Poor, limited and unacceptable detail and analysis	/ 5
Scientific support and/or connection to Grenville	Excellent	Good	Adequate	Marginal or limited	Poor or missing	/ 5

Figure 14. The 2020 Earth 231 assignment rubric

Fall 2019 Assignment Outline

Earth 231
Final Bancroft Group Assignment
Presentation dates: Nov 26 & 27, depending on lab session
Paper due date: Dec. 3rd at 4:30 pm
Paper submission: Digital copy of text uploaded to dropbox on LEARN, no paper copy needs to be handed in.
Appendix must be put at front of EIT 1009 by 4:30 on Dec. 3rd

After completing your fieldwork, it's time for your group to write a longer, more detailed geological report and prepare a short presentation on your site to give during your laboratory session. Your paper is due a few days after your presentation so you can add or modify your paper based on any insight you might gain from discussion during your presentation.

OBJECTIVES: The aim of the written report is to prepare a geological report describing your field site. The aim of the presentation is to provide a brief overview of the geology of your site, the interesting rocks you found, and its geological history to the rest of the class.

PRESENTATION DETAILS:
You have 12 minutes (max!!) to present your information to the class, followed by ~3-5 minutes for questions and discussion. You can prepare a PowerPoint or Prezi presentation, use overheads, or use whatever method you'd like to deliver the information to the class. You must include the geological map you've made of your outcrop, and an interpretation as to how it formed, but besides that it is really up to you what you present. You could include some regional geological maps, lots of pictures, and you could bring your samples to show to the class.

PAPER SUBMISSIONS
We will be using Turnitin this year. To submit your paper, your group must upload into the dropbox "Bancroft Projects FINAL Submission FOR GRADING" on LEARN. You must submit your paper in PDF format (not MS Word or other word processing formats). More information on Turnitin and how we will use it in this course can be found at the end of this handout.
The appendix for your paper will be a PHYSICAL (not digital) submission and must be put at front of EIT 1009 by 4:30 on Dec. 3rd. See details on the appendix below.

PAPER DETAILS:
Write a geological report describing your field site. Make sure to include the following:

1) Mandatory cover sheet/title page - will be posted on LEARN
2) Abstract (1 page)
3) Main body (text, ***exclusive*** of maps & figures) ~8 pages, 1.5 to double spaced, Times New Roman, Cambria or Arial size 12 font), including:
    a. Section 1: Regional Geology:
        i. A description of the Grenville province. Discuss the different subdivisions (i.e. belts or terranes) of the Grenville and make sure to indicate what part of the Grenville you site is located in
        ii. A geological map showing the Grenville Province and any further subdivisions you feel are important. Once again make sure to indicate what part of the Grenville province your site is located in.
    b. Section 2: Local Geology
        i. Section 2a) a description of the rocks AROUND (not at) your outcrop
            1. Take a look at the map you handed in in your pre field trip assignment, discuss the local context in which your site/rocks occur
            2. Include a corrected/updated version of the geological map you handed in with your pre-field trip assignment (*include a physical copy with your appendix*)
        ii. Section 2b) a description of the rocks AT your outcrop
            1. A description of what you observed at your outcrop, including
                a. a concise description of each rock unit/type you show on your map. You DO NOT need to describe each individual sample you took at your site here (this should be included in your appendix), instead you need to group your samples into logical rock units that you show on your map. These units should be described in a logical order (either oldest to youngest, or from one side of your outcrop to the other e.g. east to west, etc)

   b. a description of the spatial/age relationships between the different rocks, based on the cross cutting relationships you observed in the field. ***Use lots of photos to prove to your points/show important contact relationships***
2. A detailed geological map of your outcrop. Remember that this is a real map, and must include elements included on all maps (north arrow, co-ordinates, scale, legend with symbols, etc). Make sure to indicate where the samples you collected are from on your map. (*include a physical copy with your appendix*)

c. Section 3: Geological history
   i. How did the rocks at your site form? Make interpretations from the observation you made in the field in conjunction with current ideas you find in the geological literature. Make sure to show evidence of your group's own independent and critical thoughts. Refer to the field guide and make sure you answer any questions asked about your site.
d. Section 4: Conclusions
   i. Do not present any new ideas or information here!! Instead summaries the most important points you have made in your paper

4) References (see section below on references)
5) A physical Appendix (a box with your samples and paper copies of maps and descriptions). Make sure to label the box with your group number. Include:
   a. A well-organized box with your labeled samples.
   b. Your ***marked*** pre-field trip assignment
   c. A physical copy of a corrected/updated version of the geological map you handed in with your pre-field trip assignment (section 2a above)
   d. A physical copy of your outcrop map (section 2b above)
   e. A description of each of the samples you collected in the field (include a paper/physical copy with your box of samples)

MARKING:
A copy of the rubric used last year will be made available on LEARN. I may make minor revisions/changes, but the bulk of the rubric will stay the same. It is possible that not all group members will receive the same mark on the project, as your final mark will be influenced by your peer evaluation. This will be discussed more in class.

NOTES ON REFERENCING AND COMMON ISSUES/PROBLEMS

The top three mistakes with referencing in my experience as an instructor are:

1. **Not citing ALL sources listed in your references list WITHIN the text**
2. **Not listing ALL references cited in the text in your reference list**
3. **Not including references in figure captions if you did not make the figure**
   - **Need to place an in-text reference in the figure caption. If you have modified anything (like the map in your first report) the reference should read "*(modified from author, year)*"**

Use the style of referencing found in the Canadian Journal of Earth Sciences (APA style). Marks will be deducted for improper referencing. See "referencing format.pdf" on LEARN for format for the reference list at end of main paper. Below are samples of correct "in-text" references. If in doubt, please ask!!

- In text references:
  - One author:
    - (Parks, 2013)
  - Two authors:
    - (Parks and Lin, 2013)
  - Three or more authors:
    - (Parks et al, 2013)

Acceptable types of references include

1. Journal articles
2. Textbooks

No web references, unless it is a URL or DOI link to a published journal article This also means no online encyclopedias!!! Marks will be deducted. Use textbooks instead!!! Your own or ones from this thing call a LIBRARY.
DO NOT use this site:
http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/POP001//pop001.pdf

Using Turnitin in EARTH 231[1]

WHAT IS TURNITIN AND HOW WILL IT BE USED IN EARTH 231?

Turnitin is a text matching tool that works by comparing your written assignment with a database of millions of web pages, academic books and articles, as well as other students' papers. In EARTH 231 you will have the opportunity to use Turnitin yourself, in order to assess your draft version so that you can identify and then correct any problems before you submit your final version for grading.

How will this work?

There are two dropbox folders on our LEARN site:

1. "Bancroft Projects DRAFT Submission" dropbox.
2. "Bancroft Projects FINAL Submission FOR GRADING" dropbox.

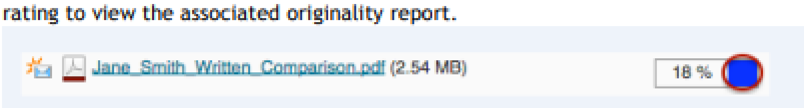
In the "Bancroft Projects DRAFT Submission" dropbox you will be able to submit a draft version of your paper and see the Turnitin originality check results for it. You can then make changes to your draft and then submit your final paper to the ""Bancroft Projects FINAL Submission FOR GRADING" dropbox.

WHEN SHOULD I SUBMIT MY DRAFT(S)?

I recommend that you submit your draft to the daft submission dropbox a few days before your paper is due. Once you submit your draft to the dropbox it might take some time (i.e., minutes, or in some cases even a day or more) to receive the Turnitin originality report. You'll need to give yourself time to interpret the report and then make any necessary adjustments to your paper before submitting your final written comparison.

How do I see the originality report?

You can view the originality report from the Folder Submissions page. Click the coloured section beside the percentage rating to view the associated originality report.



WHAT WILL I RECEIVE FROM TURNITIN?

Turitin highlights and colour-codes unoriginal content and produces an Originality Report that includes a similarity index (a percentage) indicating how much of the submission was not original. The originality report can help you identify where you might have unintentionally used poor paraphrasing when summarizing information from another source.

When the Originality Report is ready, you will see a percentage of the amount of matched (i.e., unoriginal) content. A lower percentage rating indicates that most of the content is original; a higher percentage rating indicates that much or all of the content matches content fund in other sources and require further investigation. The percentage ranges are associated with colours, as follows:

Blue: >= 0 and < 20%
Green: >= 20 and < 40%
Yellow: >= 40 and < 60%
Orange: >= 60 and < 80%
Red: >= 80 and <= 100%

HOW DO I INTERPRET THE ORIGINALITY REPORT?

The percentage itself only tells you how much of the paper is the same as other sources (i.e., how much of your content is not original): the higher the percentage, the more the assignment will require revisions. Note that there is no "safe" colour or percentage. Therefore, no percentage or colour in the originality report can fully evaluate whether text has been plagiarized. Rather than focusing solely on the percentage, go through your paper and look at the highlighted sections. Those are where some re-writing needs to be done.

[1] Modified with permission from BIOL 273 course material

In EARTH 231, and in Science in general, direct quotes are not acceptable so direct matches should be addressed before you submit your final version for grading. This means that you need to paraphrase correctly with citations in the APA style.
If you need help interpreting the originality report you can refer to the Turnitiin website http://turnitin.com/en_us/features/originalitycheck. Cumbria University also has a good video on how to interpret the Turnitin originality report:
http://www.cumbria.ac.uk/StudentLife/Learning/SkillsCumbria/DigitalLearning/Turnitin.aspx
If you need help with paraphrasing, you can seek help from the Writing Centre https://uwaterloo.ca/writing-centre/

Figure 15. 2019 Earth 231 mapping project outline and requirements.

2019 Group Marks

Table 16. Marks of the 2019 groups in the six rubric categories determined to be affected by the VFE.

2019						
Outcrop Group	Description (%)	Local map (%)	Description of rock units and outcrop (%)	Map elements (%)	Unit subdivision/accuracy (%)	Outcrop story (%)
1	80	60	60	50	50	80
2	80	80	60	60	60	60
3	60	80	60	80	80	80
4	60	80	50	80	80	80
5	50	50	60	50	60	60
6	80	80	80	80	60	60
7	60	80	60	60	80	60
8	60	100	80	80	100	100
9	80	100	80	80	80	80
10	100	100	80	80	60	80
11	80	100	80	80	80	80
12	100	80	100	80	100	100
13	60	80	80	80	100	100

2019 Rubric

Report format	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Format	Excellent, proper format	Good, proper format	Improper format	Improper format, one section missing	Improper format, many sections missing	/ 2.5
Writing style, spelling and grammer	Excellent, few or no errors	Good, some errors	Adequate, some or many errors	Marginal, many errors	Poor, many errors	/ 2.5

Referencing	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Type/appropriatness	Excellent, relevant sources	Good, relevant sources	Adequate, source could be better	Marginal, web references included	Poor, web references included	/ 2.5
Paraphrasing, use of in-text references	Excellent	Good	Adequate	Marginal	Poor	/ 2.5
Format	Excellent, proper in text references, all sources listed	Good, minor improper in text references and/or one source missing	Adequate, minor improper in text references and/or one source missing	Many improper in text references, and/or more than one source missing	Major issues with referencing	/ 2.5

Report	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2.5 points	Level 1 1.5 points	Criterion Score
Report: general persentation of data, depth and breadth	Data and interpretations presented in a logical manner, Superior grasp of subject matter	Data and interpretations presented in a logical manner, Reasonable grasp of subject matter	Data and interpretation mixed, Reasonable grasp of subject matter	Data not presented well, Some grasp of subject matter	Little to no grasp of subject matter	/ 5
Appendix	Excellent samples and descriptions, all maps and pre-trip assignment included	Good samples and descriptions, all maps and pre-trip assignment included	Adequate samples and descriptions, all maps and pre-trip assignment included	Poor samples and descriptions, all maps and pre-trip assignment included	Poor samples and descriptions and/or maps and Pre-trip assignment missing	/ 5

Regional geology: Grenville	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Description of Grenville	Excellent description of the Grenville	Good description of the Grenville	Adequate description of the Grenville	Poor description of the Grenville	Inadequate description of the Grenville	/ 2.5
Map of Grenville	Excellent map, relevant and contains all required components	Good map, relevant and contains all required components	Adequate map, some what relevant and contains most required components	Poor map, is not relevant and does not contains all required components	Missing	/ 2.5

Local geology: around your outcrop	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Description	Excellent description of the local geology	Good description of the local geology	Adequate description of the local geology	Poor description of the local geology	Very poor description of the local geology	/ 2.5
Local map	Excellent map, contains all required components	Good map, contains all required components	Adequate map, contains most required components	Poor map, does not contains all required components	Very poor map, does not contains all required components	/ 2.5

Your outcrop	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2.5 points	Level 1 1.5 points	Criterion Score
Description of rock units and outcrop	All units identified and described logically, excellent age relationships	Most units identified and described logically. Good age relationships. Some minor details missing	Some units not identified or description is lacking. Adequate age relationships. Details are missing	Poor descriptions of different units. Poor age relationships	Unacceptable descriptions of units and/or missing significant units. Not enough detail provided	/ 5

Outcrop Map	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Map elements	excellent legend and symbols	good legend and symbols	adequate legend and symbols	Marginal legend and symbols, items missing	Unacceptable legend and symbols, many items missing	/ 2.5
Unit subdivision/accuracey	Excellent amount of detail, map is accurate	Good amount of detail, map is mostly accurate	Adequate amount of detail, map is inaccurate in places	Marginal amount of detail, important details are missing	Unacceptable amount of detail, many important details are missing	/ 2.5

Presentation	Level 5 2.5 points	Level 4 2 points	Level 3 1.5 points	Level 2 1.25 points	Level 1 0.75 points	Criterion Score
Oral communicaiton skills/creativity	Excellent and/or very creative	Good and/or very creative	Adequate	Marginal	Very poor	/ 2.5
Outcrop map	Excellent	Good	Adequate	Marginal	Very poor	/ 2.5
Scientific content	Excellent	Good	Adequate	Marginal	Very poor	/ 2.5

Geological history	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2.5 points	Level 1 1.5 points	Criterion Score
The story from your outcrop	Excellent, well thought out. Reasonable analysis	Good, well thought out. Reasonable analysis	Adequate, some aspects not well thought out, or details missing. Adequate analysis	Marginal, many aspects not well thought out, or many details missing. Weak analysis	Poor, limited and unacceptable detail and analysis	/ 5
Scientific support and/or connection to Grenville	Excellent	Good	Adequate	Marginal or limited	Poor or missing	/ 5

Figure 16. The 2019 Earth 231 assignment rubric

Appendix C: Posters

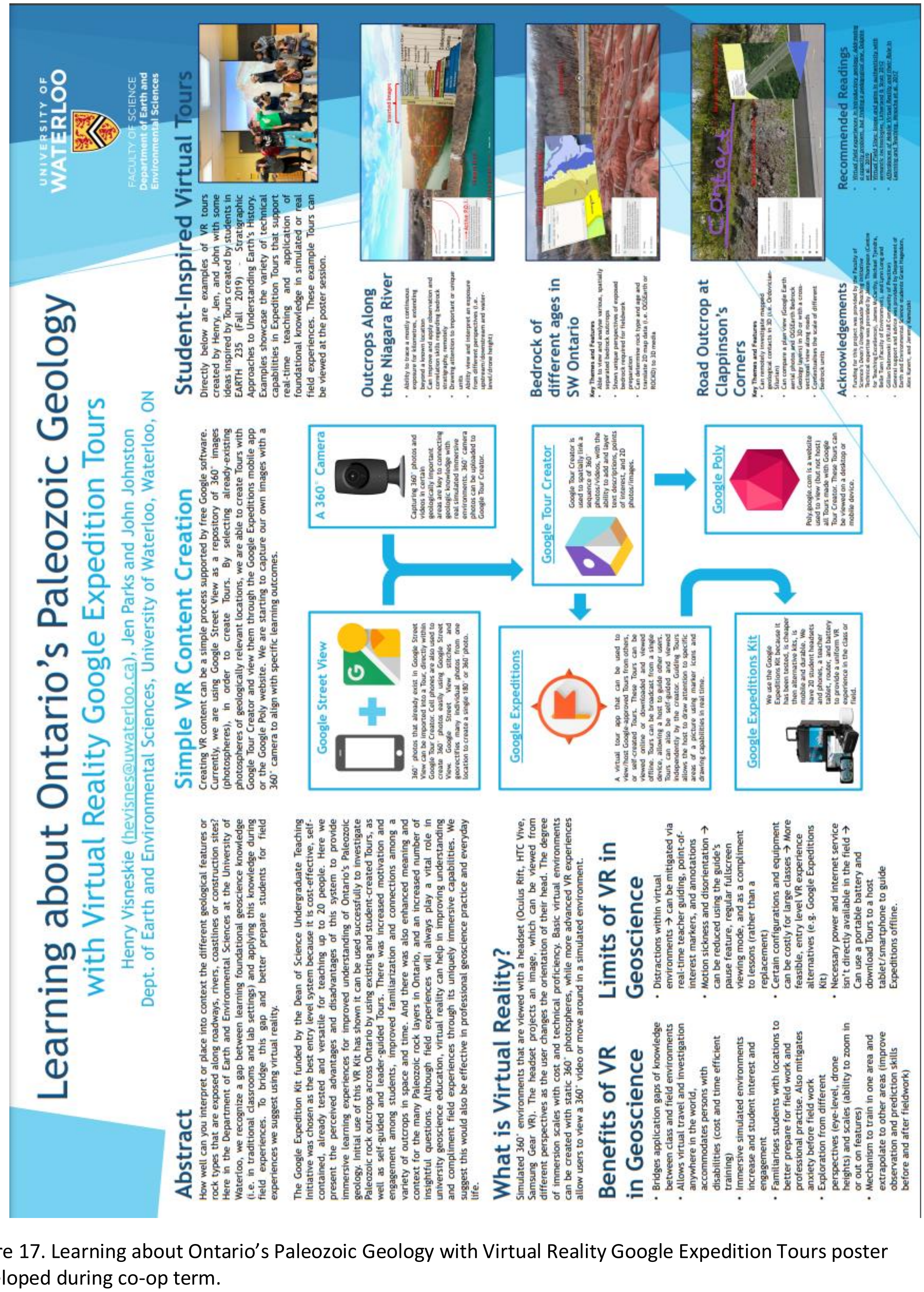


Figure 17. Learning about Ontario's Paleozoic Geology with Virtual Reality Google Expedition Tours poster developed during co-op term.

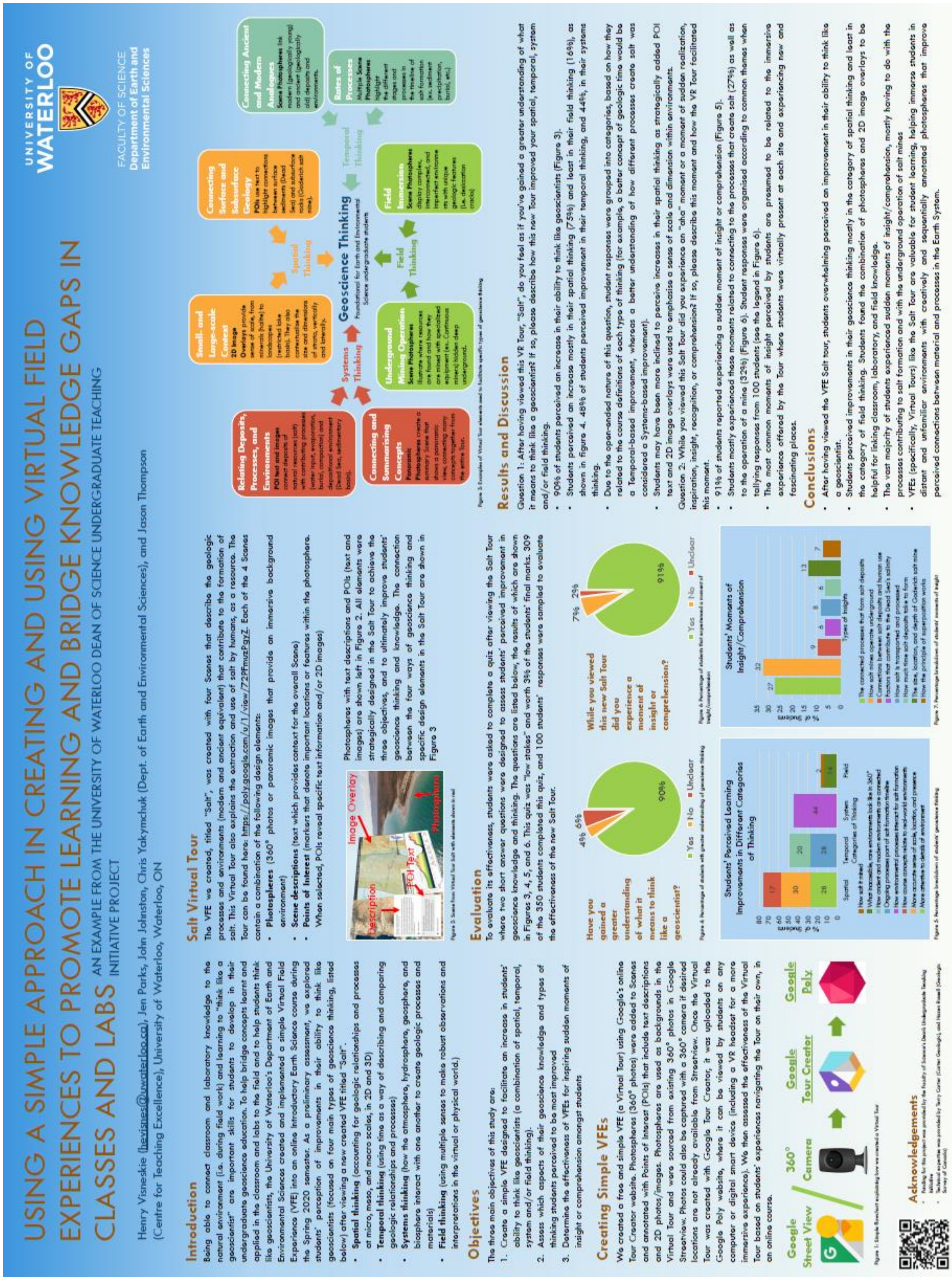


Figure 17. Using a Simple Approach in Creating and Using Virtual Field Experiences to Promote Learning and Bridge Knowledge Gaps in Classes and Labs poster created during 2020 co-op term.

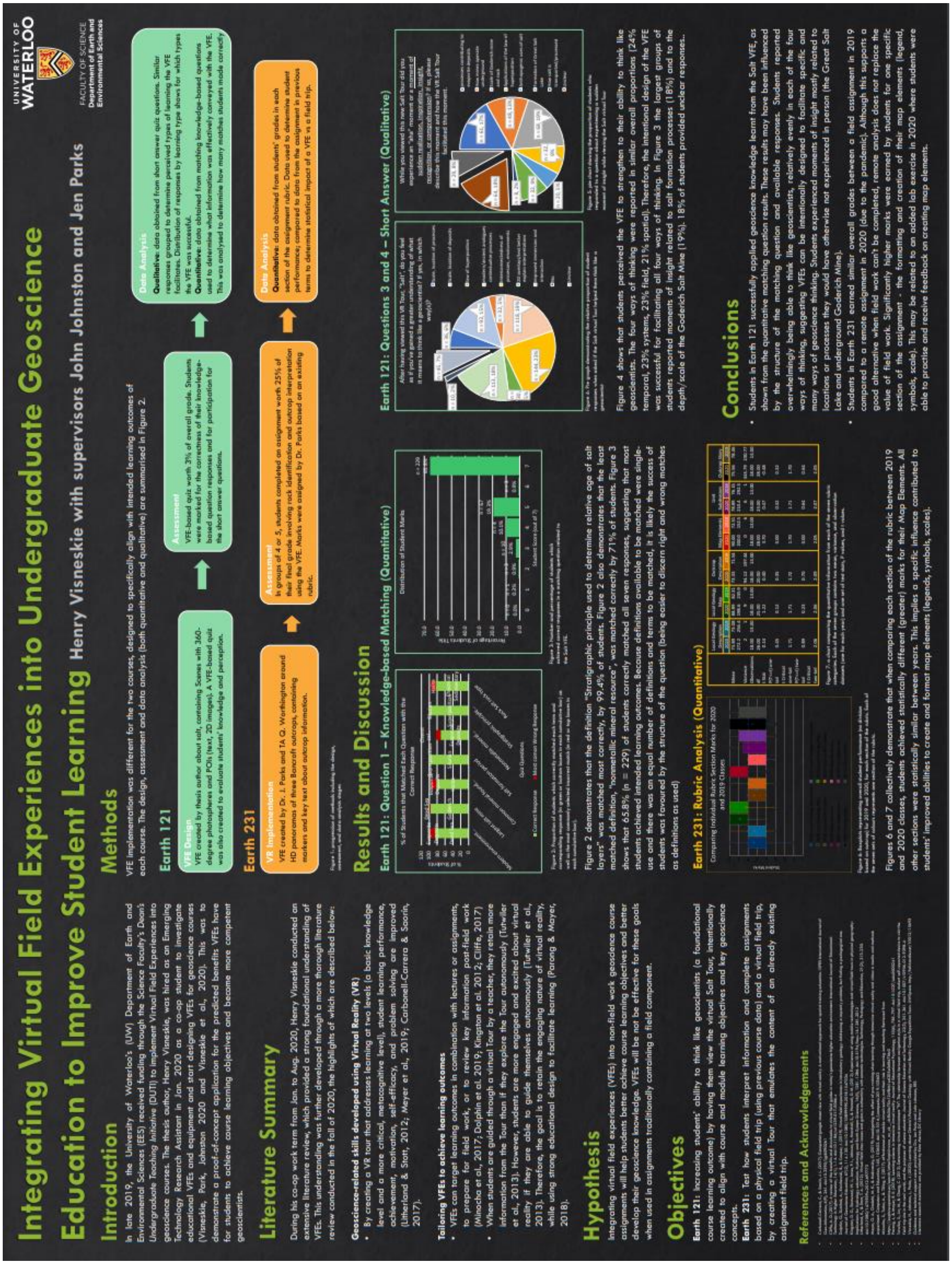


Figure 19. Integrating Virtual Field Experiences into Undergraduate Geoscience Education to Improve Student Learning poster developed for this thesis.