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Evaluation of Academic and Social Engagement in a Technology-Based Collaborative Approach to Inclusive Geoscience Field Learning

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Evaluation of Academic and Social Engagement in a Technology-Based Collaborative Approach to Inclusive Geoscience Field Learning.

by

Anita Marie Stone Marshall

A dissertation Submitted in partial fulfillment Of the requirements for the degree of Doctor of Philosophy School of Geosciences College of Arts and Sciences University of South Florida

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Dedication

“The Earth gives no higher or nobler task than to study nature, to unlock her secrets and interpret her deeds.” - Walter Manger

May we welcome all who wish to pursue this noble task.
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Abstract

Field learning is an important aspect of geoscience education to teach or reinforce concepts and skills, and the highly social experience of field work can improve learning outcomes, create networks to support future academic success, and promote a sense of belonging in the geosciences. However, field learning presents significant barriers to participation for students with physical disabilities. The introduction of digital data collection and communication devices into traditional field work settings has created new opportunities to expand access to field learning experiences such as remote collaboration; a method of undertaking field work through collaborative teamwork and the use of digital communication technology.

This mixed-method study examines the factors that influence academic and social engagement when implementing remote collaboration into a residential field learning experience for students with a range of physical abilities. The results of a quantitative video analysis indicate that cumulatively, levels of academic engagement for students using remote collaboration and participating directly in the field were similar, however the results for individual participants were highly variable. An examination of two students who participated in field work with partial direct access and remote access reveal significant differences in how engagement levels varied between the two approaches and highlight the importance of choosing inclusive strategies that are best suited to each student’s learning style and unique needs. Survey results indicate that students found the digital environment of remote collaboration conducive to positive social interaction. An analysis of interview and observation data indicates that potential influences on engagement include the academic background of participants, academic inclusion and support
from faculty, social inclusion from peers and the development of cohesive team identities and
goals, the ways in which technology was utilized, and student agency in making choices
regarding the means of participation and level of physical engagement. The results of this
evaluation indicate that remote collaboration has the potential to be an engaging means of
participation that enables a more physically diverse student population to be active participants
in geoscience field learning environments.
1. Introduction

Field trips have long been considered a critical aspect of geoscience education. Work in a natural field setting allows geology students to gain deeper understandings of geologic concepts and serve as the primary mechanism in which key skills related to data collection and geologic interpretation are taught (Elkins & Elkins, 2007; Mogk & Goodwin, 2012). It is often a required component of geoscience curriculum for students at all levels and considered to be a significant factor in the positive feelings geoscience students have towards their chosen major (Gold et al., 2003). Despite its importance, student participation in field work is prohibitive for some students due to factors such as cost, work/family obligations, and physical mobility limitations. Students with limited physical mobility face additional environmental, institutional, and social challenges that are much different than those of able-bodied students (Atchison, 2011; Hall & Healey, 2005; Hall, Healey, & Harrison, 2002).

In the past, most geology jobs required physically demanding work, and as a result were exclusive to able-bodied individuals. In the modern age, many geoscience jobs are available where physical capabilities are not a factor in job performance. However, the physical challenges of completing field-based course work and traditions of exclusion present significant barriers to students with disabilities wishing to obtain a degree in the geosciences. As a result, degrees in STEM (Science Technology Engineering and Math) with field research components have the lowest percentage of graduates who identify as disabled; estimated to be as low as 1-2% in the United States (Locke, 2005). This number is far short of the 11% of undergraduate students who identify as disabled (National Science Foundation, 2017).
With the heavy emphasis placed on physically strenuous activity, physical/mobility issues that do not pose a barrier in everyday life can easily prevent participation the geoscience field learning, meaning the number of students who may require some type of accommodation is far greater than the number of students who may be registered with disability services. To increase the diversity of the geoscience student population, inclusive methods of undertaking field work must be evaluated for their potential to provide engaging and academically worthwhile learning experiences.

1.1 Statement of the Problem

Field work is often a required component of coursework in the geosciences, and the educational benefits have been well studied (Elkins & Elkins, 2007; Gold et al., 2003; Stokes & Boyle, 2009, others). Many key concepts and vital skills such as mapping, stratigraphy, orienteering and geospatial awareness are often only taught in a field setting. Although the benefits of field work are widely acknowledged, field work has long been the domain of the able-bodied, due to the physically rigorous nature of most field exercises.

Students with mobility impairments face more than just physical barriers to fully participating in the geosciences. Long-standing traditions in the geosciences often dismiss individuals who are less physically able as not fit to be real geologists. The assumption of mobility is so deeply woven into the fabric of geology that it exerts an influence even when no overt exclusionary action has been taken. In fact, students with disabilities will sometimes choose to opt out of a field trip because they perceive their presence lessens the experience of able-bodied students (Healey, Roberts, Jenkins, & Leach, 2002). Interviews with college students with disabilities in the UK (Hall et al., 2002) and the United States (Atchison, 2011) suggest a climate of institutional exclusion and social stigma is all too common in the geosciences. Other
research suggests this unwelcoming climate permeates the broader collegiate setting (M. Fuller, Healey, Bradley, & Hall, 2004; Hutcheon & Wolbring, 2012; Taub, McLorg, & Fanflik, 2004), but is especially prevalent in science and engineering degree programs (Jenson, Petri, Day, Truman, & Duffy, 2011).

The social experience of field work has an important role in generating feelings of community and connection to the geosciences (Gold et al., 2003; Stokes & Boyle, 2009; Streule & Craig, 2016). In one study of geography students, social bonding opportunities were second only to hands-on experience in terms of what students valued most about field work (Scott et al., 2012). Most geoscientists look back on their experiences in the field with great fondness. Students often discover life-long friends, future colleagues and future mentors as a result of the social bonding that occurs. Participation in field work experiences early in undergraduate coursework has even been shown to increase engagement with peers and faculty long after the trip has concluded (Walsh, Larsen, & Parry, 2014). However, the focus on –and often glorification of - the physicality of field work can exclude students with physical disabilities from becoming full members of the cultural society within the geosciences. It can foster an environment where social stigmas, the use of demeaning language, un-accommodating course requirements and social events planned in inaccessible locations all contribute to the climate of exclusion (Hall & Healey, 2005; Hall et al., 2002). Even when these things are not present, the physical isolation of being left at the van or at the base of a mountain can turn into social isolation as the physical challenges and long hours spent together create strong social bonds amongst the rest of the students.

Traditionally, approaches to field work could be clearly described as either direct, physical field experiences, or virtual experiences through the use of digital technology.
Technological advancements in recent years have provided geoscience educators with innovative new ways to combine the direct and virtual field experience to provide access for students who would otherwise be unable to participate in field studies. This now equips educators with three options for providing any student access to a field learning environment:

1. **Direct**: Learning exercise are done on site in the field with full physical access to the study location and all places of interest, typically with a high degree of physical ability, fitness, and comfort in rugged settings required for successful completion.

2. **Virtual**: Field learning takes place fully within a digital recreation of, or remote interaction with, the study location; which can be accessed through software, virtual reality equipment, or internet resources, or other similar approaches.

3. **Remote Collaboration**: A hybrid of direct access and virtual access where field learning is accomplished through partial access to the field site, the use of digital communication technology and collaboration with partners working in other locations.

Remote collaboration is a new and developing technique and the literature to date has focused primarily on development and general results from trial runs (Collins, Davies, & Gaved, 2016; Collins, Gaved, & Lea, 2010; Gaved et al., 2008; Gaved, McCann, & Valentine, 2010; Stokes et al., 2012). This approach has great potential for revolutionizing access to field learning, but before this approach is adopted into geoscience field learning environments as a means of expanding access and inclusion, it must be examined for the capacity to provide an academically and socially beneficial experience for all participants.

Regardless of the approach to field learning, engagement is a necessary component of a successful learning experience (O’Malley et al., 2003). The importance of engagement to positive educational and affective outcomes in virtual field experiences has been established in
the literature (Joel et al., 2004; Saini-Eidukat, Schwert, & Slator, 2002; Stokes et al., 2012; Whitelock & Jelfs, 2005), but has yet to be studied in the unique setting of remote collaborative field learning environments. This study provides a unique opportunity to examine this new approach to field learning in depth and evaluate its potential to provide an academically and socially engaging field learning experience.

1.2 Research Questions

Geoscience field work provides students with invaluable opportunities for academic growth and social bonding, both of which are important factors for student success in the geosciences. In order to develop and refine real-world solutions to access for all students in the geosciences, we must gain a better understanding of the effectiveness of specific approaches to providing alternative access to field learning environments. To that end, this research is constructed to address the following guiding research questions:

1. Does remote collaboration through technology enable academic and social engagement in the field learning activities?

2. What are the factors that influence academic and social engagement when incorporating remote collaboration in field learning activities?

This study examines the remote collaborative approach to field learning from both sides of the student partnership utilizing the technology: less mobile students operating in a limited geographic space within the field site, and more mobile students with full access to the field site. Further, by examining three case studies where the approach to remote collaboration was implemented in different ways, a more robust picture of the potential impacts, challenges and applications of this approach is created and discussed.
1.3 Definition of Disability

Disability can refer to a wide range of personal conditions to include mobility impairments, sensory impairments, or cognitive impairments. This terminology comes with significant social baggage that cannot be lightly dismissed. For some, this term is considered inappropriate because the word disability is a societal label that inherently implies a deficiency or other-ness to individuals whose bodies function outside of socially accepted norms (Healey et al., 2002; Hutcheon & Wolbring, 2012). However, there is no agreement as to what terminology could adequately replace the word ‘disability’; as each suggested replacement carries its own system of meaning which may not align with an individual’s worldview. The terms ‘differently-abled’ and ‘ability-diverse’ are sometimes used instead, but some people who identify as disabled do not like either of those terms. This document will use the word disability because it is the term used in legal descriptions regarding accessibility (Devlieger, 1999), and is widely accepted by people to whom the term applies (Lynch & Groombridge, 1994).

It is also important to note that this study does not use official status such as being registered with state or university services as a part of the definition of disability. Many individuals who would not be considered ‘disabled’ in everyday life have a mobility impairment that would inhibit their ability to fully participate in geoscience field work. Therefore, my definition includes people with mobility limitations due to age, injury, or medical condition (permanent or temporary) regardless of any sort of officially recognized status. See Section 2.2 for an examination of the Models of Disability.

This study focuses specifically on physical disabilities; conditions that limit the degree to which a person can physically traverse or interact with the landscape or manipulate objects. ‘Physical disability’ and ‘mobility impairments’ are both commonly used to describe individuals
with some degree of limitation in movement (Gardiner & Anwar, 2001), and both are considered acceptable descriptive terms within the disability community. For the purposes of this study, the term ‘students with disabilities’ refers to physical disabilities and does not include individuals whose impairments are sensory, neurocognitive or psychological in nature unless otherwise stated.

1.4 Summary of Study

This study was undertaken within a larger NSF-funded study in the GEOPATH program (Award no. 1540652). The GEOPATH project, “Engaging Students in Inclusive Field Experiences via Onsite and Remote Partnerships”, was a two-year project examining many aspects regarding the development and execution of accessible geology and the development of best-practices for geoscience faculty regarding inclusion for students with disabilities (see Section 3.1). Within the GEOPATH project, my research focused on an evaluation of engagement for students using a collaborative technology-based approach to participation in field learning experiences and the unique challenges of engagement for students that have difficulty accessing direct field learning environments. This study has social and institutional impact by providing an initial evaluation of a developing technique for expanding access to field learning experiences to a broader student population, thereby allowing students with physical disabilities to become more equal academic and social members of the geoscience learning community. This study also examines engagement for students undertaking a more traditional (i.e. direct) approach to field work and contributes to the literature regarding engagement in field learning. There are two key strengths of this study. The first is the opportunity to examine a new approach to geoscience field learning which has the potential to provide a rich and engaging field experience that does not seek to replace traditional field learning, but rather allows more students a means to participate in it.
Secondly, this study contributes to the extremely small body of literature regarding the experiences of students with disabilities in STEM fields and specifically in the geosciences.

1.5 Significance of Study

The use of technology to provide access to the field for students with disabilities presents great promise for providing an engaging field learning experience in a way that has previously not been possible. But these new approaches must be examined to ensure that they can provide an engaging and meaningful learning experience. This study contributes to the literature of geoscience education by exploring a developing technology-based approach to field learning, and also contributes to the relatively sparse literature regarding marginalized groups within the geoscience and STEM fields at large. Examining the potential for engagement in a novel approach to inclusive field learning provides valuable insight into the design and implementation of field courses aimed and broadening participation for a diverse student population.

Additionally, this study contributes to a better understanding of the influences on engagement in field learning environments, which are beneficial to any field learning program.

A recent international study revealed that 30% of the global white-collar workforce identifies as having some type of disability (Sherbin, Talor Kennedy, Jain-Link, & Ihezie, 2017). Individuals with disabilities are reported to make up just 9% of the geoscience workforce in the US (National Science Foundation, 2017). The workforce demand for STEM majors in the US has remained strong while the number of graduates in the natural sciences and engineering has declined (Callahan, Libarkin, McCallum, & Atchison, 2015). Increasing the number of students who have access to STEM degree programs is vital to meeting workforce demand. This study examines one approach that could improve inclusion for a broader demographic within the
geosciences and contributes to the greater conversation about diversifying the geosciences workforce.

It is also important to note that individuals with disabilities are found in all racial, ethnic, gender and age groups, which makes the challenge of access relevant to all discussion of broadening participation. Institutions of higher learning play a key role in defining the positions of traditionally marginalized groups within the social hierarchy at large (Barton, 1997), and by excluding specific groups of people from full participation in the collegiate setting, it reinforces the idea that stigmatization and exclusion are socially acceptable (Gardiner & Anwar, 2001; Giddens, 1998). Scientific innovation flourishes in settings of diverse viewpoints and backgrounds (Gilley, Atchison, Feig, & Stokes, 2015), yet the voices of individuals with disabilities can only be added to the geosciences when existing barriers to their participation are examined, addressed and dismantled. The research outlined in this proposal aims to examine some of the barriers to participation and evaluate a potential approach for overcoming some of those barriers.

The potential benefits of this study reach beyond access for students with disabilities. Providing a means of alternative access to geoscience field learning opportunities when physical participation is not possible for any reason should be something that all geoscience departments have the capacity to offer. And while the approach examined in this study incorporates partial access to the field and real-time communication, the results of this study have the potential to contribute insights to completely virtual access to field learning, as well as technology-mediated learning.
2. Review of Literature and Theoretical Framework

This chapter outlines relevant research on the topic of field-based learning, issues of accessibility in higher education and the geosciences, and the potential barriers to full participation and engagement that students with physical disabilities may face when undertaking field-based course work. Relevant literature is discussed, and the location of this study within the existing body of research is defined.

2.1 Theoretical frameworks

This study uses the research frameworks of Grounded Theory and Critical Theory. The data is analyzed under the framework of grounded theory, which does not begin with an initial hypothesis, but rather aims to produce hypotheses as outcomes of the study (Gall, Borg & Gall, 1996). This approach of generating theory from systematic research works well for investigations of new or developing pedagogies where robust literature is not available to inform a meaningful hypothesis about a specific phenomenon.

This research also falls under broader sociological framework of Critical Theory, which focuses on examining and questioning the assumptions that underlie widely accepted but exclusionary or oppressive cultural practices in educational settings (Gall, Borg & Gall, 1996; Kumashiro, 2002). Critical theory has been applied to research in the geosciences in other studies, especially in topics related to field work (Atchison, 2011; Carabajal, 2017; Semken & Brandt, 2010). Critical Theory seeks not only to question the existing social structure within an educational setting, but also to empower those who have been marginalized and bring a sense of equality to all participants. Kincheloe & McLaren (1994) describe the social environment of
education as one in which “[w]e are all empowered, and we are all unempowered, in that we all possess abilities and we are all limited in the attempt to use our abilities (p.290)”. This perspective allows Critical Theory to work very well with the social model of disability.

Field work takes place in a highly social setting, and therefore can be examined through a social framework. Streule & Craig (2016) propose that the social experience and the learning experience in geoscience field work are so completely intertwined that field learning should be conceptualized and examined through a Social Learning framework. This framework builds upon the idea of communities of practice, described by as “groups of people that share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting in an ongoing basis (Wenger, McDermott, & Snyder, 2002, p.4)”. In short, this theory examines learning as taking place within a social collective rather than the experience of an isolated individual (Lave, 1996).

2.2 Models of disability: Medical vs. Social

There are two ways of approaching studies regarding access and inclusion for people with disabilities: medical and social. Each one comes with its own understanding of the problem, and not only define the perspectives used to examine the issue, but also by extension “…who can speak, when, where and with what authority (Ball, 1994, p.21)”. It is therefore important to summarize both approaches to the subject and locate this study within the context of these models.

The medical model of physical disability focuses on an individual’s ‘deficiencies’; essentially framing the issue around the ways in which an individual falls short of a medically defined perception of ‘normal’. The medical view of disability gave rise to such terms as handicapped and crippled to refer to people with mobility disabilities. These labels reinforce the
mindset that disability is primarily a medical condition to be treated, pitied, or stigmatized and assumes that physical attributes are the most defining aspect of an individual (Hutcheon & Wolbring, 2012). For many years, the medical model was the only model used in disability research.

The social model of disability takes the focus off individual limitations, and instead frames the issue as one of systematic institutional and societal exclusion (Oliver, 1996). In this model the root of the problem lies with society and its inability to treat all people as equal members deserving equal access. In this socially-focused framework, barriers to access are the result of societal mindsets and institutional practices that inhibit full participation by people of all abilities.

While it would simplify the issue to focus solely on the societal barriers that maintain the marginalization of people with disabilities in higher education, personal and medical barriers to participation cannot be overlooked. To disregard that disability is in part a medical issue leaves out an important piece of the access/inclusion puzzle, especially where travel and field work are concerned. Some disability advocates express the dangers of ‘disability as social construction’ as ignoring real and important problems that must be considered (Devlieger, 1999). For example, in a survey of geography students with physical disabilities in the UK, one of the biggest barriers to participation in field work was the fear of a medical condition worsening while in the field far from medical facilities (Hall & Healey, 2005). This fear touches on two barriers that are not social in origin: internal fears related specifically to the medical aspect of one’s disability, and the risk involved in traveling outside of readily available medical help with a pre-existing medical condition. By ignoring these unique medically oriented barriers to participation, we fall into the trap of de-humanizing the problem and lumping all people with disabilities into a single
category. To fully understand all the necessary components required to create a truly inclusive field-learning environment for students with disabilities, this study is located primarily within the social model of disability while acknowledging the highly individualized needs related to the medical aspect of some disabilities.

2.3 Barriers to participation in the geosciences for students with disabilities

Students with disabilities face numerous barriers to participation in collegiate STEM (science technology engineering and math) disciplines (A. Lee, 2011). Despite these barriers, a study in 2011 showed that one in five students who identify as disabled will initially select a STEM program when declaring a major (A. Lee, 2011). Because field work plays a significant part in geology curriculum, students with disabilities are often discouraged from pursuing geology as a course of study. Within STEM disciplines, the lowest percentage of disabled students are found in the disciplines considered field intensive (Hall et al., 2002). Barriers to full participation in field learning can be divided into four categories: environmental, institutional, social, and personal. The topics addressed in this study fall primarily within the environmental and social categories, yet it is impossible to examine a topic related to students with disabilities conducting field work without addressing some topics that fall within the bounds of institutional or personal barriers. All students are confronted with each of these barriers to some degree, which is why some scholars argue that by addressing these issues for students with disabilities, where they are often the most extreme, we can also improve the field work experience for everyone (Healey et al., 2002).

2.3.1 Environmental Barriers.

Environmental barriers refer to physical obstacles that prevent an individual from participation. Where geoscience field work is concerned, the environment itself is often the
biggest environmental barrier. Field work often takes place in rugged and remote landscapes where it is assumed students can fully navigate the locality. Even for students with mild-moderate disabilities who show no signs of mobility impairment in their daily lives, their experience in the field can be dramatically different from their able-bodied peers. For example, if a key concept is discussed at the top of a mountain accessible by long hike over rough terrain, that student misses out while he or she sits at the bottom of the hill and waits for everyone to come back. This can have a chain reaction of negative consequences for the student regarding conceptual understanding.

Because field locations are often in remote, undeveloped areas, it is not feasible to remove all potential environmental barriers. However, a study location is always chosen by the trip planner, and it is the planner’s choice to visit places that afford access to a wide or narrow range of students.

2.3.2 Institutional Barriers

Institutional barriers emerge from university or departmental practices that discourage or disallow participation. Within this category, policy and information barriers can both work against students with disabilities.

Policy Barriers.

On campus, the Americans with Disabilities Act (1990) creates a legal imperative to remove barriers to participation and prohibits discrimination of an individual on the basis of disability whenever feasible (ADA Title III, 1990). However, field work falls into a gray area when it comes to issues of access. Field work is not typically done on campus, but in many legal aspects are considered an extension of the classroom and campus, as are the vehicles used to transport students. In the United States, accessibility legislation is vague enough that issues of
legally required accommodation are often side-stepped by excusing a student with disabilities or changing the designation of the trip from required to optional. Some departments may also have policies designed to avoid potential liability issues by not allowing students with disabilities to participate in potentially dangerous environments (Healey, Jenkins, Leach, & Roberts, 2001). While inclusive field work practices are not mandated in the United States, a number of professional societies such as the American Geosciences Institute have voiced support for the ideal of creating access to geoscience academic and career pathways (see Appendix A for official Position Statement and a list of signatory societies).

In the United Kingdom, there are explicit legal imperatives for intuitions of Higher Education to make field work more accessible (Healey et al., 2002). Precept #11 of the Higher Education Code of Practice for Students with Disabilities states “Institutions should ensure that, wherever possible, disabled students have access to academic and vocational placements including field trips and study abroad (Czapiewski, 2002, p.6)”. The Scottish Higher Education Funding council has an entire chapter devoted to providing accommodation on field trips and study abroad activities; stating that “Inclusive field trip design will envisage a variety of potential participants and accommodate as many varied needs as possible without compromising the educational objective of the trip (Strathclyde, 2005, p.2)”. Because of the legal requirements to improve access to field work, much of the relevant literature on students with disabilities in the geosciences comes from the UK.

When bringing up issues of legal obligations of inclusion, it cannot go without saying that inclusion may require some amount of financial expenditure beyond the typical costs of a field trip. In the UK, grants at both the federal and university level are available to individuals with disabilities as well as academic departments to pay for the extra cost that may be involved
with accommodation (Healey et al., 2002). Currently, no such funds exist in the American collegiate setting. As a result, cost can be cited as a legitimate undue burden under ADA (1990) regulations that excuses the universities from making accommodations in some cases (Livingston, 2000).

**Information barriers.**

Another way that institutional practices can create a barrier to students with disabilities is by failing to provide specific information about the trip ahead of time. Studies in the tourism industry found that the inability to obtain detailed information about a location of interest was found to be a significant deterrent to traveling to national parks and other outdoor points of interest amongst people with physical disabilities (B. Lee, Agarwal, & Kim, 2012; Yau, McKercher, & Packer, 2004). These findings are echoed by students with disabilities in the geosciences who cited this as a primary source of anxiety prior to undertaking field work (Hall & Healey, 2005). When these concerns dominate thought processes, learning objectives become secondary.

**2.3.3 Social Barriers.**

Social barriers are the actions or oversights that create an unwelcoming atmosphere; intentional or not. The social climate of higher education in is considered by many to be unfriendly to students with disabilities, and a number of studies have shown that that the actual number of students with disabilities at any given university may be much higher than the official count, because students chose not to register as disabled due to fears that disclosure would jeopardize their admission into the school or reflect negatively on their social identity (Baron, Phillips, & Stalker, 1996; Newman et al., 2011).
The topic of social marginalization in the geosciences first appears in the literature regarding the social challenges that women faced when doing field work (Maguire, 1998; Nairn, 1996; Sparke, 1996), and more recently has been examined as it relates to students with disabilities (Healey et al., 2002). Field work continues to be perceived as a very ‘macho’ endeavor (Bracken & Mawdsley, 2004; Stokes & Boyle, 2009) where extreme landscapes, physical challenges, and primitive living conditions are all considered rites of passage by many field instructors. Because of the heavy emphasis on participation in field learning environments that are often physically challenging, students in the geosciences who do not measure up to the ideal of the physically fit, rugged explorer can be socially marginalized. A large survey of geoscience professionals by Atchison & Libarkin (2016) revealed a pervasive culture of exclusion towards individuals with disabilities within the geoscience community and a widespread belief that physical ability was a requisite for a successful geoscience career. With so few individuals who identify as disabled in the geosciences, the issue of social exclusion in the geosciences is self-propagating. A study found that the earlier an able-normative student had opportunities for educational and/or social interactions with disabled peers, the more likely they were to have individuals who identify as disabled as part of their social circle in college (Ash, et al., 1997), yet these interactions are unlikely to occur in the geosciences.

2.4 Novelty Space

The term Novelty Space was coined by Orion and Hofstein (1994) to describe the level of familiarity a student has with the cognitive, psychological and geographic (i.e. environmental) requirements of a field trip. The less uncertainty a student has regarding the learning outcomes, the physical requirements for successful completion and the location, the smaller the novelty
space. A small novelty space indicates an optimal learning environment, a large novelty space represents conditions where students are unlikely to make meaningful cognitive gains.

Geoscience field work can present a significant number of ‘unknowns’ for students, especially on trips that take place over multiple days far from home. Mogk & Goodwin (2012) revise the three components of novelty space specifically for geology field work as:

1. Where are we going geographically and geologically?
2. What am I expected to do in this setting?
3. What will my personal comfort and/or safety level be? (p. 140)

Some researchers have argued that the social aspects of geoscience field learning can have such a significant impact on learning, that a fourth component of Novelty Space, Social Novelty, is required to understand all the potential influences on learning in the field (Elkins & Elkins, 2007; Stokes & Boyle, 2009). Social Novelty describes the potential influence of a learner’s understanding/comfort level with the social and affective aspects of field learning (Stokes & Boyle, 2009).

In residential (i.e. multi-day) field work, novelty space will typically start out large, and diminish over the course of the field experience as students acclimate to new landscapes, schedules, and social environments (Xie & Garner, 2009). An especially large novelty space has been linked to negative student opinions about field work (i.e. Cotton, 2009), yet the majority of geoscience novelty space studies focus on the affective influence of novelty space, and do not examine the assumed link between novelty space and engagement or learning outcomes.

Uncertainty regarding conditions and requirements in the field can negatively affect any student’s ability to learn, but it can present significant barriers to students with mobility limitations who rely on information provided by the trip planners to decide if they could
successfully complete, or even participate in, field work. Without prior knowledge of what to expect, the students are left to guess (and worry) about terrain, field conditions, and personal safety in the event they are left behind somewhere on the trail. This may be yet another reason that students with disabilities choose not to participate in field work, even when given the opportunity.

2.5 Engagement & Learning

Engagement in educational settings can be thought of as “the degree of attention, curiosity, interest, optimism, and passion that students show when they are learning or being taught (Abbot, 2016)”. The importance of engagement to learning outcomes cannot be overstressed. Some argue that a study of engagement is a necessary precursor to a study of educational outcomes, because without engagement, learning is unlikely to occur. Reschly and Christenson (2006) explain that engagement is also an important component to retaining students from traditionally underrepresented groups in academic programs. O’Malley (2003) explains that any new educational format should first be checked for satisfactory levels of engagement before any claims regarding educational outcomes can be made. The lack of engagement, on the other hand, has been linked to poor academic performance and a high risk of dropping out of an academic program (e.g. Davidson, 1996; Reschly & Christenson, 2006).

While it can be discussed broadly in terms of its influences on various aspects of the overall learning process, engagement is typically conceptualized as multi-dimensional. The number and type of dimensions included in definitions of engagement vary in the literature. An excellent review by Fredricks and McColskey (2012) summarizes the development of two, three and four-dimensional models of engagement which may include behavior, emotion, cognitive, academic, or psychological (or affective) dimensions. Each of these terms have been
conceptualized in very different ways by researchers, which makes definitions of these terms difficult and inhibits comparisons of study results across the literature (Fredricks & McColskey, 2012).

Social engagement is a conceptualization that borrows from education research as well as social research regarding learning communities. In education research, it is located under the larger umbrella of psychological/affective engagement. Essentially, it is synonymous with the term “Belonging” which Goodenow (1993) defines as “a student’s sense of being accepted, valued, included, and encouraged by others (teachers and peers) …and feeling oneself to be an important part of the life and activity of the class (p.25)”. In short, social engagement is the sense that a person is included in, and belongs to, a learning community (e.g. Tinto, 2003; Wenger et al., 2002).

Academic engagement is defined as the time spent on tasks used by the learner to build knowledge or better understand the content presented in the learning activity such as taking notes, asking questions, discussing material with team mates, working on assignments, etc. (Reschly & Christenson, 2006).

2.6 Field-based learning in the geosciences

In the geosciences, the field is any place where supervised learning takes place via first-hand experience outside the constraints of the traditional classroom setting (Kent, Gilbertson, & Hunt, 1997). A field site can be a place that is physically travelled to, explored virtually via technology, or a combination of the two. For this study, field work/field learning is specifically referring to activities that are a required component of a course or degree track. The focus of this study is on required field work because it is a very real barrier to completing a geoscience undergraduate degree for students with disabilities (Gilley et al., 2015). For the purposes of this
study, ‘field work’ does not include field research, which is typically completed as a graduate student and has a much more individualized goal of collecting data for a thesis or dissertation, which has its own set of unique challenges.

Field work provides a valuable experience that allows geology students to physically interact with rock outcrops and structures in an open setting, or “direct experience with academic content within a relevant context (Streule & Craig, 2016, p.102)”.

Surveys at recent professional meetings found that the majority of geoscientists (93% at a national meeting and 79% at an international meeting) felt that fieldwork was a necessary component of geoscience training (Atchison & Libarkin, 2016). When paired with proper classroom instruction, it provides a beneficial way for students to bring a variety of concepts together into a more cohesive understanding of geologic processes. Field work provides an opportunity to reinforce classroom concepts for better retention (Atchison, 2011; Kent et al., 1997, others), and a chance to learn how the science of geology is conducted by learning field techniques and interpretation skills critical to a conducting geologic research (Kent et al., 1997). Just as important as the skills and knowledge building, field work is a critical factor in building a student’s identity as a member of the geoscience community (Mogk & Goodwin, 2012; Stokes & Boyle, 2009; Streule & Craig, 2016).

The learning goals of field work are highly variable – no two field work experiences are the same. Direct geoscience field work often entails learning the skills to construct field maps and interpret geologic structures, characterize and identify rocks and minerals and interpret their meaning in the context of structure and stratigraphy (e.g. Puckette & Suneson, 2009; Stokes & Boyle, 2009; Vance, Trupe, & Rich, 2009). For students doing field work as part of an experiential learning program, the goal may be a deeper connection to general subjects (Stumpf,
Douglass, & Dom, 2008), and to foster “diligent curiosity (p.100)” – a habit of persistent inquisitiveness in a particular subject (Ham & Flood, 2009). For project-based field work, the goal may be to teach students the process of geoscience research (e.g. Gonzales & Semken, 2009; May, Eaton, & Whitmeyer, 2009) or industry-desirable technical skills (e.g. Kelso & Brown, 2009). With such a variety of learning goals there is no universal method of assessing a student’s learning experience in the field. Without the ability to easily compare learning outcomes across different approaches to field learning, it is difficult to determine what approaches or techniques produce the best results. One factor critical to successful learning outcomes that can be examined in any type of learning environment is engagement.

2.6.1 Engagement in field learning.

In direct field learning environments, engagement is often a natural product of the activity and/or location itself. Still, there are many factors that can influence student engagement in the field. Boyle et al. (2007) proposed that a student’s positive interest in field work makes them naturally more academically engaged and therefore positively affects their learning outcomes. However, in a study of geomorphology undergraduates, Stumpf et al. (2008) showed there was no statistical significance in learning outcomes related to a student’s self-reported interest in doing direct field work. This disagreement may be the result of the kinds of approaches to learning each of these studies was built on. Deep learning, is fostered by positive affective responses to the learning environments while surface learning can be motivated by external influences such as grades (Stokes & Boyle, 2009). Stumpf’s research was focused on introductory-level students where most of the learning objectives were surficial in nature (i.e. facts and memorization) and did not attempt to measure signs of deep learning, which may explain why the two studies are not in agreement on the influence of student interest on learning.
The role of instructors in promoting engagement is also important. In a study of a residential field mapping course, Stokes and Boyle (2009) found that students valued the time spent with experts as providers of guidance and support, and that interaction with faculty increased confidence, which in turn increased motivation and engagement. A study of college students in STEM fields found that instructors influence feelings of motivation, confidence, or anxiety in the way they introduce and guide learning experiences (Jenson et al., 2011). The study focused on students with disabilities and noted that rapport with instructors was the single biggest factor in their feelings of self-confidence, persistence through difficult assignments, and motivation to invest in the learning process. Further, the role of mentorship is an important mechanism to create a sense of social belonging in communities of learning (Callahan et al., 2015). This may be especially important in the case of novice learners in a geologically complex terrain, where students may struggle with spatial understanding and structural mapping activities (Ishikawa & Kastens, 2005; Riggs, Lieder, & Balliet, 2009).

Collaboration can play a key role in promoting academic engagement in learning activities and fostering a positive social environment where collaboration can flourish may play a role in the quality of learning outcomes (e.g. Stokes & Boyle, 2009; Streule & Craig, 2016). In a study of physical Geography students, Fuller (2006) showed that students felt that working in teams allowed them to develop a better understanding of concepts than they would have on their own. De Paor and Whitmeyer (2009) have noted that teamwork increases confidence and cuts down on time-wasted in the field. When there are others to consult, the weaknesses of one student can be immediately addressed by others. For example, a student who is having trouble orienting themselves may have a teammate who is better at map reading. Opportunities to collaborate on field research that has a broader impact than simply the completion of a learning
assignment, such as publications or community impact, have also been shown to have a significant impact on engagement in the current learning activity as well as future academic engagement (Gonzales & Semken, 2009; Marshall, Gardner, Potti, & Nourse, 2009).

Physical challenges are also considered to play a role in engagement in direct field learning environments as students bond over shared hardships (Stumpf et al., 2008). Challenging academic and physical conditions in the field create a highly interactive environment that promotes social bonding, friendships, and professional networks to develop (Mogk & Goodwin, 2012). Exercises often take place in remote and rugged terrain with no shelter, no facilities, and often no cell phone reception where students are expected to take care of themselves in an environment few have experienced before. Many instructors see this as an important part of the training process because it tests each student’s ability to handle the traditional perception of the physically demanding lifestyle of a geologist (Ham & Flood, 2009; Sisson, Kauffman, Bordeaux, Thomas, & Giegengack, 2009).

In a commentary by Streule & Craig (2016), the authors explain that field trips are socially intensive experiences where geological discussion takes place within a social context both in the field and during down time, as students are living and working together in unique environments. This unique social setting “is to a geoscience student what a hospital is to a medical student (p.103)” in terms of promoting their identity and skills as practitioners (Streule & Craig, 2016). Students who have no opportunity to participate in field work are therefore missing out on a key component of the geoscience learning experience. For students with mobility impairments to gain the same educational and social benefits as fully mobile students, either a study location must be chosen with access in mind (e.g. Atchison & Gilley, 2015; Gilley
et al., 2015), or alternative approaches to field access must be employed that provide a comparable level of engagement.

Social engagement is also important to improve the broader social climate for traditionally marginalized groups. In a study of early college students, a combination of social and educational contact between students of different physical abilities resulted in greater mutual understanding, social bonding and beneficial collaborations across ability levels (Ash et al., 1997).

2.7 Virtual Field Work

A Virtual Field Trip (VFT) is a digital representation of a field site, real or fictional, through which students engage in learning activities. VFTs have been developed for educational purposes since computers became widely available in classrooms (Grant, 1993; Kent et al., 1997), and today are most commonly used to introduce or reinforce concepts taught in the field before or after a physical field trip (e.g. Kelly and Riggs, 2006; Stumpf et al., 2008; Granshaw, 2011). Virtual access to exotic or inaccessible locations have been shown to generate feelings of excitement and act as motivators for learning (Bursztyn, Walker, Shelton, & Pederson, 2017; Edelson, Pitts, Salierno, & Sherin, 2006). Recent research suggests that VFTs have the potential to provide a viable alternative to the direct field experience in terms of cultivating student interest in the geosciences (Bursztyn et al., 2017). However, VFTs differ widely in terms of their goals, design, and approach to the learning experience; and not all offer the same potential in terms of learning or engagement.

Technology has diversified the options for simulating field environments to include everything from websites (Stumpf et al., 2008), to multi-user virtual environments (Dieterle and Clarke, 2007; Nelson and Erlandson, 2008) to state of the art fully immersive reconstructions of
field sites (e.g. Schuchardt and Bowman, 2007; Atchison & Feig, 2011). For the most meaningful and successful VFT experience, engagement must be encouraged throughout the learning activity. Unlike direct field work, in which a high potential for engagement is a natural by-product, engagement in a virtual environment must be intentionally addressed in the design and execution of the learning activity.

2.7.1 Engagement in virtual settings.

A VFT must incorporate two key elements to promote engagement: immersion – the sense of experiencing the virtual environment (Moore & Gerrard, 2002), and interaction – the ability communicate with others and/or influence the activities or environment of the virtual setting (Joel et al., 2004; Saini-Eidukat et al., 2002). Of the two, interaction appears to be the more influential factor in promoting engagement and a positive affective experience in a virtual setting (Corter, Esche, Chassapis, Ma, & Nickerson, 2011; Joel et al., 2004; Saini-Eidukat et al., 2002; Stokes et al., 2012; Whitelock & Jelfs, 2005). The ability to communicate with teammates or other users within a VFT builds camaraderie and is an important factor in creating a positive learning experience (Arrowsmith, Counihan, & McGreevy, 2005; Coughlan, Adams, Rogers, & Davies, 2011; Jackson & Winn, 1999). Students must feel as if they are actively involved in the learning activities of the trip, not just remote spectators (Hine, Rentoul, & Specht, 2004; Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005);

A synthesis of the literature regarding VFTs suggest that the highly variable range of immersion and interaction in VFTs means that some VFTs may present a more engaging experience than others (Figure 2.1). For example, a basic website with text, photos, and videos may get do an adequate job of presenting the content, and even have a certain amount of immersion but the lack of opportunity for interaction by the user puts them at a disadvantage
when it comes to engagement (Carabajal, Marshall, & Atchison, 2017). VFTs within computer-created Virtual Environments, such as those designed with gaming software, have the capacity to provide a great deal of engagement. Multi-User Virtual Environments have an even greater capacity for engagement because of the added ability for users to interact with other participants within the virtual environment. Immersive systems (such as VR headsets, projection walls) are difficult to place within the spectrum of engagement. While there can be a high level of immersion (e.g. Jackson & Winn, 1999), content engagement can become challenging when users are so engrossed in - or overwhelmed by - the virtual environment that they may struggle with where to focus their attention for learning activities (Lin, Tutwiler, & Chang, 2011; Nelson & Erlandson, 2008). Choosing the best type of VFT for the desired outcomes requires thoughtful consideration of both the intended experience as well as the desired level of academic content and social engagement.

Figure 2.1. Interpretive comparison of engagement in virtual and alternative field learning environments based on a synthesis of the literature. Larger boxes indicate a high degree of variability in the published results for the indicated method. (Graphic by Marshall, published in Carabajal, Marshall, & Atchison, 2017, reprinted with permission)
2.8 Remote Collaborative Field Work

By combining the positive benefits of participation in direct field trips, the benefits to learning provided by collaboration, and the ability to provide learning opportunities virtually, field work can be approached with a method that combines aspects of both direct and virtual field learning. The outcomes of an evaluation of remote collaboration during the RAFT (Remote Access Field Trip) Project, indicated that engagement for remote participants was heavily dependent on the assigning of active roles for each participant (Bergin et al., 2007), and that academic engagement could not be maintained as simply a spectator to events in the field (Hine, Rentoul, & Specht, 2004).

In the UK, the Enabling Remote Activity (ERA) project examined the potential use of remote communication technology to provide alternative access to geoscience field work for students with mobility limitations. In this project, students parked in a vehicle near the field site were able to communicate with partners in the field via wireless technology (Collins et al., 2016; Gaved et al., 2008; Gaved et al., 2010; Stokes et al., 2012). Being in the same landscape as the rest of their classmates and participating in field activities in real time through the sharing of photos, videos, text and voice were big contributors to social engagement and feelings of inclusion. However, the collaborative dynamic was extremely one-sided, with the remote learner completely dependent on their field partner to provide data, context, or any other information from the field. A potential solution to this inequity was developed in the Out There In Here project which sought to give remote participants a more active role in the learning experience (Adams et al., 2011; Adams, Davies, Collins, & Rogers, 2010; Coughlan, Adams, & Rogers, 2010; Coughlan et al., 2011). In this iteration, students worked in two groups: one in the field and one at an indoor base station. The base team had access to a wide variety of resources such
as maps, books and digital information, while the field team had access to physical outcrops and field observations. Both teams worked together by sharing information in near real time to complete an assigned project. This was a big improvement as far as academic engagement, but took the remote learner(s) completely out of the field setting, and again the remote students were dependent on the field students for data collection.

A new approach, where all participants in remote collaboration are in the field working at locations with varying degrees of accessibility has great potential for both academic and social engagement by including students of all mobilities in the field work process. The social experience of travelling and experiencing a field site with the rest of the group, as well as the opportunity to physically interact with the field location, even if only to a limited extent, adds rich opportunities for engagement. Because the technology allowing real-time streaming communication in the field is relatively new to the consumer market, few groups within the geosciences are currently experimenting with this technology. Much of the existing literature focuses on the developmental and technological aspects of remote access, and there has been little work to examine if and how these systems provide a rich and engaging field learning experience.

2.8.1 Social Presence & Engagement in remote learning environments.

In literature from the field of computer science and education technology, social engagement is fostered when the virtual or remote environment allows for ‘social presence’ - the ability to project one’s own personality into the virtual environment and interact with others in a meaningful way (paraphrased from Garrison, Anderson, & Archer, 1999; Warburton, 2009). Kreijns et al. (2014) summarize it as “being perceived as a ‘real’ person, capable of acquiring social identity, having purposeful conversations, and building relationships (p.5)”. Social
presence is not engagement, but it is a pre-requisite for engagement. When social presence is established, it creates feelings of trust and belonging, a sense of community and good working relationships (Kreijns, Kirschner, Jochems, & Van Buuren, 2007). Research by Gunawardena & Zittle (1997) indicate that social presence is a strong predictor of participant satisfaction in digital environments.

The majority of studies regarding social presence in the literature focus on text-based communication amongst student teams in online coursework that is primarily asynchronous in nature (Kreijns, Kirschner, Jochems, & Van Buuren, 2004b; Kreijns, Kirschner, & Vermeulen, 2013; Kreijns et al., 2014; S. Lee, 2014). Studies that have examined communication techniques in online learning environments indicate that social engagement is much stronger when synchronous, real-time communication is used (Ocker & Yaverbaum, 1999; Rockinson-Szapkiw, 2009).

As reliable options for videoconferencing became widely available, a new option for synchronous participation was developed. Blended learning environments, where students participate in live classroom settings through video conferencing and virtual spaces, have also been examined in the literature (Bower, Dalgarno, Kennedy, Lee, & Kenney, 2015; Bower, Kenney, Dalgarno, Lee, & Kennedy, 2014). These blended learning environments have much in common with the remote collaboration approach to field learning, with two key differences. First, in blended online learning, the interactions are primarily instructor-student, but in remote collaboration activities such as those being examined in this research, interactions are primarily student-student. And secondly, the blended learning described in the literature takes place in an on-campus or urban setting where the number of potential technical challenges to enabling a stable live-streaming connection between participants are significantly smaller than in a remote
field setting. Nevertheless, these blended collaborative environments provide insight to the potential influences on engagement in similar settings.

Some studies on blended learning show that high levels of social presence can be achieved in real-time synchronous virtual environments (Garrison et al., 1999), yet others caution that while the potential for engagement may exist, synchronous communication does not automatically facilitate social or emotional engagement without active encouragement and guidance from faculty (Butz, Stupnisky, Peterson, & Majerus, 2014; Szeto & Cheng, 2016). In literature from the field of computer-mediated learning, there are two schools of thought as to the best approach for facilitating engagement and strong group performance for situations where members of a group are dispersed geographically and connected through technology as outlined by Hiltz et al. (2006). The first approach is one of structure and design where users collaborate within a framework of rules or ‘best practices’ and guided within the framework by internal designs in the software being used, or by external instructions/guidance. The second approach is to view the communication technology software as simply the space in which social interactions occur and allow collaborative groups to self-organize into roles that best suit the task and personal preference. Determining the setting in which each of these approaches may be the most effective is an on-going topic of research.

The idea of ‘social presence’ has not yet been brought into geoscience education literature, but a relevant phenomenon was noted when Coughlan et al. (2011) reported that adding a low-resolution live video stream during remote field work greatly improved the engagement of remote participants. The resolution was not fine enough for direct use in learning activities, for example looking at outcrop details or rock textures, but did provide remote
participants a chance to communicate with students in the field in real time; strengthening their connection to the field activities.

2.9 Summary and Location of this study within the literature

Field work is a vital part of geoscience curriculum. Direct field work provides the opportunity for students to fully engage in a setting that naturally fosters content and social engagement. But the emphasis on physically intensive field trips presents significant barriers to students with disabilities, or any type of mobility limitation. These barriers include environmental, institutional and social components which work together to produce an unwelcoming climate for students with disabilities. This study is located within the social model of disability while acknowledging the highly individualized needs related to the medical aspect of disability.

There are three approaches that can be applied to delivering geoscience field learning experiences to students. Direct physical field work offers a deeply social, engaging learning experience. Virtual field trips allow students more accessible opportunities for field learning, yet often lack the depth of engagement of a direct field experience. Remote collaborative access combines direct and virtual field learning into a new way of undertaking field work by augmenting physical access with access through technology to interact with partners in the field in real time.

Academic and social engagement are both critical components of a successful field learning experience. Studies have measured engagement in direct and virtual geoscience field learning, but engagement in the blended learning environment of remote collaboration is not yet part of the literature.
This study contributes to the literature of geoscience education by examining engagement in a novel approach to field learning, namely remote collaboration, and also contributes to the literature regarding engagement in more conventional direct geoscience field learning experiences. It also contributes to the relatively sparse yet growing field of literature focusing on the development of accessible geoscience learning opportunities and the experiences of students with disabilities within the geosciences.
3. Methods

Remote collaborative field work is a method of undertaking field work through a combination of teamwork and the use of digital communication technologies (Section 2.8) that allows geographically separated teammates to collaborate on field learning exercises. This study is designed as an evaluation of field learning activities that incorporate remote collaboration as an approach to inclusive field learning.

3.1 Research Design

This study was conducted as an internal evaluation, meaning the researcher had an active role in the program being evaluated (Cousins, Donohue, & Bloom, 1996; Gall, Borg & Gall, 1996). The guiding evaluation questions were developed by considering the potential broader applications of the approaches being developed within the GEOPATH project and by identifying potential stakeholders in the outcomes of those broader applications. One of the important outcomes of the GEOPATH project is to illustrate how inclusive field experiences can be designed by incorporating technology and collaboration. To determine if this approach could be implemented in their own field programs, stakeholders such as geoscience educators, department heads and universities need information regarding the educational merits of the approach.

In determining the focus of this evaluation, a key aspect of the learning experience had to be identified that had a broadly understood importance to the educational process and would be universally available for study in any of the very different settings in which the learning activities of the GEOPATH project took place. Engagement was chosen as the focus of the
evaluation because it is a necessary component of successful learning experiences (O’Malley et al., 2003), and could be examined and compared across a range of educational settings.

To evaluate the potential for remote collaborative field work to provide an engaging field learning experience, this study focuses on two questions:

1. Does remote collaboration through technology enable academic and social engagement in the field learning activities?
2. What are the factors that influence academic and social engagement when incorporating remote collaboration in field learning activities?

The following sections outline the context, participants, field locations, and data collection procedures used to address the research questions. Qualitative and quantitative methods were used to address both questions in this mixed-methods study.

3.2 Context for the Research: the NSF-funded IUSE-GEOPATH project

This study was undertaken as part of an over-arching series of investigations conducted as part of a multi-institutional IUSE-GEOPATH program, “Engaging Students in Inclusive Field Experiences via Onsite and Remote Partnerships” (see Appendix B for official project summary). The goal of this 2016-2017 project was to examine a range of aspects related to the development and execution of approaches to accessible field geology through the use of digital communication tools and collaborative learning. Two components remained the same in each of the approaches/interventions piloted during the project. The first was the use of technology for communication and data collection, such as digital tablets and wearable cameras. The second was the use of collaborative student teams combining able-normative participants with participants who identify as disabled.

Traditional field notebooks were replaced with digital tablets for duration of the project for several reasons. The tablets allowed for the use of digital data collection apps that provided
improved opportunities for collaboration and provided the potential for enhanced inclusion through digital communication, streaming video and photo sharing. The tablets also provided students with a customizable interface to address accessibility-related needs. The wearable cameras were added to the digital toolkit after students informally tested the potential applications of one camera during the first field trip and enthusiastically requested their addition for the second-year field trip.

Several types of collaborative team structures were employed for field work over the course of the project. Two structures were assigned by the researchers; rotating partners and fixed teams of four. A third developed informally, which the students referred to as the ‘amorphous group’; an open format that allowed students to form and reform their own groupings during a field activity.

In the first-year field trip to Arizona, learning exercises were generally short (one day or half day), introductory level activities similar to those in weekend or one-day undergraduate field trips. Findings from the first year were used to determine which approaches to refine and examine in more detail in the second year of the project. The second field trip took place in western Ireland the following year and was conducted with more advanced learning exercises, as are typical of summer or semester-long field courses. These exercises required student teams to collect and synthesize complex geologic data into finished products such as maps and reports.

Based on the findings of the first year, three learning exercises were designed for the second year, each with a different approach to collaboration through technology (see Section 3.4). The first exercise employed digital data collection, but no communication in the field. The second exercise used digital data collection and asynchronous collaboration between team mates at separate locations within the same field site. The third exercise utilized synchronous remote
communication to enable collaboration between students located near the field site in vehicles with students in the field. The second year also expanded the technological toolbox of the project with the addition of a portable Local Area Network to allow wireless communication within the field site (see Collins et al., 2016; Collins et al., 2010 for technical details on this system).

This project was a collaboration amongst many researchers, and each had a specific area of focus. As a result, some details that would no doubt be of interest to readers such as the names of apps used for data recording and note-taking, or specific details regarding the learning exercises are omitted in deference to upcoming publications.

This project was an ideal setting to examine the research questions regarding engagement through technology in the field-based learning environments because each exercise was designed with a different approach to the use of technology as a means for collaboration. The differences in the approach and structure of each exercise allows for comparison across approaches and formats rather than focusing on one single implementation of the concept. By examining different approaches to remote collaboration, potential influences on engagement are brought to light that may have otherwise gone un-noticed in an examination of a single approach.

All data collection and research for the GEOPATH project was conducted under IRB authorizations through James Madison University (ID #16-0030) with data processing and analysis conducted for this study at the University of South Florida (see Appendix C for IRB Approval Letter).

3.3 Participant characteristics and sample size

The IUSE-GEOPATH project team (prior to the researcher’s involvement) recruited two populations of students, both of whom participated for the duration of the two-year project and
took part in all field activities. These participants were chosen before the researcher’s involvement in the project and are therefore considered a sample of convenience.

The risk to participants was no more than in a typical Field Geology Course. Participation was fully voluntary and did not count towards a grade or course credit for the students.

**Cohort 1- Students without physical disabilities (SWoDs).**

A total of 6 able-normative geoscience students were selected based on some limited experience in a geoscience program. These students were recruited from geoscience programs at two and four-year colleges across the United States and Canada. At the start of the project, these students had completed their second-year geoscience requirements but had little to no field experience. One of the participants from this group left the project during the second-year field trip and was not replaced, leaving this cohort with 5 students for most of the second field trip. A graduate student was assigned to stand in as a field partner when pairs when needed for learning activities.

**Cohort 2- Students with physical disabilities (SWDs).**

A total of 6 students who identify as disabled were recruited to represent a range of physical disabilities from mild to extreme. Based on the goals of the project, the cohort was restricted to students with mobility or motor-skill disabilities. Students with sensory or cognitive disabilities were not included. Ideally, students in this cohort would have been at the same second-year level as the students without disabilities. However, the population of students with disabilities within the geosciences at that level of study is small, so students for this cohort were recruited at all undergraduate levels, with preference given to those in their second year of study.
3.4 Description of Field Sites and Student Assignments

3.4.1 Year 1 – Arizona.

The first year of the funded project featured a field trip to northern Arizona in May of 2016. The trip was a week-long field study of the regional geology in northern Arizona. Field work initiated with a daylong stratigraphic study of the Red Rock area around Sedona, with stops at the Coconino National Forest Visitor Station, Slide Rock State Park and the Oak Creek Canyon overlook. A visit to the Grand Canyon provided a different type of opportunity to examine regional stratigraphy, utilizing the Trail of Time exhibit. Volcanology field work in the San Francisco Volcanic Field focused on lava-flow and cinder cone morphology and included stops within the Sunset Crater National Monument and at SP crater. The last day of the field trip involved a visit to Meteor Crater, AZ to examine the morphological features of a large impact crater, and a short stop at Montezuma’s Well to examine karst and groundwater-related features of the Verde Valley. See Appendix D for more detailed descriptions of the first-year locations and activities.

At each of these locales, the specific approach to the use of technology varied. Some variations were intentional, and others were adaptations made to accommodate unexpected conditions and/or schedule changes. The approach to student groupings was to use rotating partners. Students worked in teams of two – one from each cohort – to complete the day’s activities. The next day, partners were re-assigned, so each person had the chance to work with everyone in the other cohort at some point.

The first year’s field activities were primarily designed to pilot and evaluate the potential of several technologies and approaches, so there were not opportunities to study engagement specifically related to remote collaboration strategies. However, the activities and approaches
used during the first year’s trip greatly informed the planning and activities of the second-year trip. The focus of this study falls primarily within the second-year field trip, but relevant portions of the group interview and observations from the first year are included in the qualitative analysis outlined in Section 3.5.3.

3.4.2: Year 2 – Ireland.

In the second year of the GEOPATH project, field work took place at three locations along the coast of western Ireland in Counties Clare and Galway. At each location a different approach to collaboration and technology use was employed, based in large part on the findings of the previous year’s field research. The following section provides brief descriptions of the location, student assignments, and the specific approach to the use of the technology for collaboration and access.

Site 1. Cliffs of Kilkee.

The cliffs of Kilkee are a series of exposed Carboniferous age sedimentary units along an open bay facing the Atlantic Ocean near the coastal town of Kilkee in County Clare. (Figure 3.1). The units that comprise the bluffs show abundant evidence of penecontemporaneous deformation and other soft-sediment features, as well as interesting depositional bed forms and non-sedimentary features such as faults and mineral-filled fractures. In some places, the cliffs are eroded out in a stair-step arrangement, and students who were physically able could explore many of these units up close. A fully accessible trail runs along the top of the cliffs with excellent views of many of the larger-scale features exposed in the cliffs.
At Kilkee, students were not assigned to teams, and could choose to work alone or with others. Students were given several hours to explore the field site at their own pace and ability. They were all directed to find and document three interesting geologic features to share with the group. Wi-Fi was not available at this location, so data were collected and stored for sharing later. The morning after the field exercise, students took turns giving short presentations to the team on what they found. Digital tablets were used to provide data collection, documentation and note-taking in an easily sharable format (Figure 3.2). The tablets also provided alternative means of note-taking for those with motor skill limitations, such a text-to-speech in place of typing, and annotated photos in place of sketches.

Figure 3.2 The use of technology to collect data in the field at Kilkee. (a) Students using digital tablets for data collection and note-taking at Kilkee. (b) a participant’s annotated photo of bed forms (c) an example of a digital reading of strike and dip taken with the tablet and added to a student’s notes with an annotation.
**Site 2. Recess, Connemara.**

The second field exercise focused on metamorphic rock identification and structural geology and took place in the Connemara region of County Galway near the town of Clifden. Connemara is a geologically complex region comprised of heavily deformed meta-sedimentary units. This rural location, called ‘Recess’ by the locals, was selected because it has a history of being used as a field-mapping project area for undergraduate geology field camps. Work in this region took place at three field sites. On the first day, students were divided by cohort, and worked at two separate sites. The SWD group documented outcrops at a local Fish Hatchery (Figure 3.3), while the SWoD group started at a different location and hiked several miles to examine outcrops near an abandoned mining operation (Figure 3.4). The second and third day of the mapping exercise took place at a third location, a rural field site accessed by a dirt road that used to be a railroad track (Figure 3.5). Because of the previous rail line, there are several road cuts directly on the trail that were accessible to all students. More outcrops were located along a river, which required a hike through boggy, rocky terrain.

Students were divided into working groups of four, comprised of two participants from the SWD group, and two from the SWoD group. As the SWD team members worked at outcrops along the road, the SWoD team members collected data at outcrops along the river. Working in pairs ensured that students were not alone when working in different parts of the field site. The three-day assignment was to describe the outcrops and collect relevant field data to produce geologic maps, and to report on their findings as a team. The working pairs from each team were not in contact during the first field day and were in intermittent contact during the second and third days. Teams had time to work together in the evenings to combine and interpret the data collected at their respective locations.
Each student had a digital tablet, and six wearable cameras were rotated among group members. These technologies provided students with the ability to share data, photos or videos with their teammates, as well as to collect data, write field notes and make observations with adaptive methods that worked for a range of physical abilities and learning styles (see Figure 3.6 for some examples). Strike and dip measurements were also collected digitally. Rather than carrying a pocket transit, students took measurements by placing the tablet flat along the plane of dip and using an app to record the strike and dip. These stored measurements could be downloaded in the evenings and used to create a collaborative structural map of the field site.
Figure 3.5. Site 3 of the field mapping exercise near Recess, County Galway, Ireland. Outcrops were located in two areas (marked in yellow), separated by difficult terrain. Student groups could communicate using their tablets through a portable local area network (LAN) that provided local Wi-Fi connections (circled in white).

In order for students to communicate via video chat and photo sharing in the field, wireless connections had to be established between their devices. No cellular networks were available, so wireless communication between digital tablets was achieved by setting up a local area network (LAN) of wireless access points mounted on temporary tripods around the field site. This network allowed devices within the field site to communicate wirelessly, but did not connect to the Internet.

Figure 3.6. Use of technology at the Recess field site. (A) taking a strike and dip measurement with an app. (B) Sketching apps for drawing and sharing. (C and D) Communication through video and photo sharing apps. (E) an example of structural mapping and data collection with digital mapping software.
**Site 3. Renvyle Point.**

The last exercise in Ireland was a one-day study of the glacial features of coastal County Galway. Field work took place at Renvyle Point and was followed by a driving tour of the glacial landscapes of Killary Harbor and Lough Nafioey. Renvyle Point is a rocky beach with an outcrop of actively eroding glacial deposits. The outcrop, which was the focus of the exercise, required a short hike over rocky terrain (Figure 3.7). Poor weather further lowered the accessibility of this location with cold and extremely windy conditions.

![Figure 3.7](image)

**Figure 3.7.** Ireland field site #3, Renvyle Point, County Galway. Student groups worked together via remote collaboration between the outcrop and the vehicles. Photo by S. Eriksson, used by permission.

Students worked in the same teams assigned for the Recess mapping project. Two team members were stationed in a van parked at the edge of the field site, and two members hiked out to an outcrop of glacial deposits that was not visible from the parking area. Students were given approximately an hour and a half to gather data and document the outcrop for a report. Instructors emphasized that all team members worked synchronously on the assignment, which required the remote students to fully rely on the use of the real-time communication technologies for successful completion (Figure 3.8). This condensed, targeted assignment provided an opportunity for detailed, focused investigation of the user experiences during a remote collaborative approach to field learning.
Figure 3.8. Synchronous remote collaboration from vehicles nearby the Renvyle Point field site. (A) Using a hand radio for clearer audio communication, (B) reviewing photos sent from the field in real time.

3.5 Data Collection

To address my research questions, data were collected during both the first and second year field trips, in May 2016 and May 2017, respectively. Decisions about data collection were guided by two considerations; the potential usefulness of the resulting information in examining student engagement, and the desire to minimize any potential to cause disruption in the activities or timeline of the field trips. Qualitative data were collected in the first year, in the form of observations and interviews. Observation and interview data were collected the second year of the project, and additional qualitative data was obtained from open-response survey questions. Quantitative data collected in the second year were collected by survey and video analysis.

3.5.1 Video Footage.

As outlined in Section 2.5, academic engagement is conceptualized as the time spent on tasks used by the learner to build knowledge or to better understand the content presented in the learning activity, such as taking notes, asking and answering questions, and discussing materials (Reschly & Christenson, 2006). To quantify the extent of student academic engagement in remote and direct field learning environments, wearable cameras were chosen as a non-disruptive approach to data collection. Student-driven video recording has been proposed as
superior method of data collection for examining the student experience in the field, as it provides in-the-moment perspectives often lost in interviews and reflections (Cotton, Stokes, & Cotton, 2010).

Three sets of video footage were collected for analysis. The first set records students using the remote collaboration method to participate in field work from vans parked at the edge of the field site during the Renvyle Point exercise (n=4). Three pairs of students worked in 3 separate vehicles during the exercise. One camera failed, so two video files (footage of four students total) were available for analysis. Both of these video files are approximately 40 minutes in length. The cameras were set up inside the vehicles in a location where audio and visual information from both team members could be obtained in the same field of view.

The second set of video data were collected by SWDs with partial access to the Recess field site (n=2). One student wore the camera, and the other student was in the field of view. These two students had access to outcrops along the roadway, but no other area of the field site. One of these students was physically able to access the outcrop, and the other student could navigate to within 0.5m – 2m of the outcrop but was not able to interact with the outcrop directly. The footage covers approximately 40 minutes of time in the field towards the end of the exercise. The two students observed in this video were also recorded participating through remote access at Renvyle Point.

The third set of video data were collected by cameras worn by SWoDs who had full access to the field site at Recess (n=5). During the time recorded on camera, these students were not using remote communication to collaborate with their teammates on the road. Instead, the footage captured was true to many field geology mapping projects where students navigate the field site with a partner collecting data. One partner in each pair wore the head-mounted camera
on continuous video mode. For each video, two students were analyzed with the observation protocol; the one wearing the camera and the one in the field of view, with the exception of one student who was working with a graduate assistant instead of a student partner. Each of the 3 cameras collected approximately 80 minutes of footage each. This is twice the length of time of the footage collected in the other two sets of video data, but this was not considered problematic because the final data set is displayed as percentages of total time analyzed and is not a minute-by-minute comparison.

3.5.2 Survey.

The Sociability Scale (Kreijns, Kirschner, Jochems, & Van Buuren, 2004a), a survey designed to measure social presence, was administered after participants used the remote collaborative approach to complete the exercise at Renvyle Point. As outlined in the literature review, social presence is not equivalent to engagement, but is a necessary component for engagement in technology-based learning environments (Section 2.8.1). The Sociability Scale attempts to measure the degree to which users feel personally connected to the activities and individuals on the other end of the remote communication link.

The Sociability Scale survey was given to all participants at the end of the second-year field trip (n=11, see Appendix E for Survey as administered). The only intentional modification done to the quantitative items was to change how the virtual experience was referred to, as our participants were not familiar with the terminology used to describe the remote learning environment in the original survey. One question was omitted from the survey due to an error when loading the survey onto the digital administration software, leaving 9 of the original 10 items in the survey. Two free response follow-up questions were added to the survey. These
open-ended items were not included in Kreijns’ (2004) Sociability Scale and are un-validated items.

3.5.3 Interviews.

Group interviews of the student participants were recorded as audio data and transcribed. Two types of interview formats were used: a full group interview with all students and faculty at the end of the first-year field trip, and focus group interviews with students from each cohort (SWDs and SWoDs) at the end of the second-year field trip. These interviews were designed to cover a range of topics of interest to the faculty working on the project (see Appendix F for Interview prompts from both years).

The full group interview (n=12) was facilitated by the GEOPATH external project evaluator at the end of the first-year field trip. All faculty and support staff were present and participated in the group interview as well. At the end of the second-year field trip, students were divided into focus groups based on which cohort they belonged to: SWDs (n=6) and SWoDs (n=5). These interviews were conducted simultaneously in separate locations. The lead PIs of the GEOPATH project were not present for these focus group interviews, which were each co-lead by a faculty member and a graduate student. To diminish the possibility of influencing participant responses, the graduate students co-led student groups that differed from their own disability affiliation; the researcher co-led the interview of the SWoD cohort, and the able-normative graduate student co-lead the interview of the SWD cohort. Interviews were administered at the end of each field trip, recorded as audio data, and transcribed.

3.5.4 Observations.

Observations of student interactions and experiences were collected in the field during the entirety of both week-long field trips by video recording, hand-written notes, and note-taking
apps on a mobile device that was protected by a pattern-recognition screen lock. Daily observations were consolidated and typed up each evening on a password protected laptop. Personal reflections on the field trip were typed up at the conclusion of each trip.

3.6 Data Analysis

This mixed-method study uses both quantitative and qualitative data to examine academic and social engagement in field work that incorporates remote collaborative learning. Quantitative data from video analysis is used to compare outward signs of both academic and engagement across different modes of conducting field work. Quantitative data were also gathered from the Sociability Scale survey. Qualitative data were obtained from participant interviews, the open-response questions on the social presence survey and observation notes.

3.6.1 Video Data analysis.

Engagement can be challenging to measure in a way that makes it possible to compare results across learning environments. One solution to the challenge of comparing engagement is to use a standardized approach to analysis such as is the STROBE observation protocol developed by O’Malley et al. (2003) for use in collegiate level health professions courses. The STROBE observation tool was originally designed to examine randomly selected students in large classroom settings where upwards of 50 groups of students are available to observe. However, it has been adapted by others to use in a variety of learning environments and has been shown to be well suited for use in comparative studies of different learning environments including collaborative groups (e.g. Kelly et al., 2005).

STROBE is not an acronym, but rather reflects the idea of using brief, illuminating flashes of observation to document engagement during a learning activity. Observations are done at timed intervals over a set period of time called a cycle. At each observation cycle, the subject
is observed for 4 short intervals, between 10 and 20 seconds, within the cycle. For this analysis, five-minute cycles with four 10-second observations were used. At each interval, the observer looks for engagement-related behavior exhibited by the selected student (e.g. talking, reading, listening, writing, organizing notes, other) and to whom the behavior is directed (facilitator, other student, whole group, self). In between intervals, observers make notes about what is going on in the group and classroom, so the quantitative results have context.

Video data was initially tabulated into the percentage of time a student exhibited signs of Engagement or Disengagement (e.g. Kelly et al., 2005). However, as the analysis progressed, further revision to the classification scheme was needed to more accurately examine questions regarding student engagement in this unique learning environment (Table 3.1). The category of Disengaged was divided into two categories; Technical and Disengaged. Given the focus of this research on students with disabilities, it was important to distinguish between needs-based distractions and voluntary distractions, so within the Disengaged category, time spent on self-care or other issues related necessities relating to a participant’s disability were also noted (see Appendix H for modified STROBE observation spreadsheet).

**Table 3.1. Engagement Categories developed for the modified video observation protocol.**

<table>
<thead>
<tr>
<th>Academic Engagement</th>
<th>Taking notes or measurements, making observations, collecting data, asking topical questions, discussing material out loud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Engagement</td>
<td>Non-academic conversations, making jokes, telling stories</td>
</tr>
<tr>
<td>Technology Engagement</td>
<td>Efforts directed at learning how to use a program or app, receiving assistance related to technology use, troubleshooting, waiting on programs to load or frozen screens, etc.</td>
</tr>
<tr>
<td>Disengaged</td>
<td>Behavior unrelated to academic or social activities such as staring off in the distance, ignoring team mates, wandering off.</td>
</tr>
</tbody>
</table>
The modified observation protocol was applied to a total of 360 minutes of video footage. For the Direct, full participation group, 80 minutes of footage were analyzed for each participant (n=5). For the Remote participants, 40 minutes of footage were analyzed for each participant (n=4). Two more participants participated remotely, but due to a camera failure, there is only 25 seconds of footage from early in the exercise and five minutes at the end of the exercise, which is not of sufficient length for a meaningful analysis with the observation protocol. The analysis produced a quantitative data set reflecting the percentage of time each student exhibited behaviors related to academic or social engagement, the time spent learning or troubleshooting technology tools, and the time where no signs of engagement are exhibited during three different approaches to participation: remote access, partial Direct field access, and full Direct field access.

Video recordings of students participating remotely at Renvyle point during the remote collaboration exercise were transcribed for qualitative analysis of dialogue and actions. Dialog was fully transcribed, and actions and body language were also described. Footage of students participating directly in the field were annotated but not fully transcribed. Along with detailed observation notes, these transcriptions provide qualitative support for the quantitative results of the video analysis. Observation and transcription data from the videos are presented alongside the STROBE analysis results in Section 4.1 and are not included in the larger analysis of qualitative data presented in Section 4.3.

Due to a limited number of cameras, students using the various means of participation in field work were not filmed simultaneously. Students participating directly in the field with full or partial access to were recorded on different days during a structural geology mapping exercise at Recess, and students participating remotely were filmed during an exercise that involved
documenting and interpreting glacial deposits at Renvyle Point (see Section 3.4 for location descriptions). While the focus of this analysis is not on learning or skills related to specific types of geology specialties, it should be noted that the learning exercises were significantly different.

3.6.2 Survey Data Analysis.

Quantitative Social Presence survey data were aggregated into two groups: SWDs working from a stationary location, and SWoDs out in the field. Due to the small sample size, advanced statistical analysis was not possible, but basic comparisons of the results between the two groups can still be made. The results of the free response survey questions are presented along with the quantitative data from the survey in Section 4.2 and are not included in the analysis of qualitative interview and observation data presented in Section 4.3.

3.6.3 Qualitative Data Analysis.

The qualitative data comes from multiple sources: a full-group interview at the end of the first field trip, two focus group interviews – one with each cohort (SWDs and SWoDs), and observational data from both years. The qualitative data collected for this research is extensive and touches on many topics. For the purposes this research, data relevant to academic and social engagement was the primary focus of the analysis.

Qualitative data collected during interviews and observations were analyzed using a descriptive coding and categorizing approach (Saldaña, 2015). Material was either categorized into each major category and was then re-evaluated and re-coded with progressively more specific descriptive codes, or specific codes were organized into unifying categories and sub-categories. After several iterations of sorting, this analysis produced a categorization scheme organized under two major categories; data relating to experiences during the GEOPATH project (Table 3.2), and data relating to experiences outside of the project (Table 3.3).
Table 3.2. Qualitative topical categories related to student experiences during the GEOPATH project.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-Category</th>
<th>Significant Descriptive Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals</td>
<td>For the Project</td>
<td>Conceptualization of project goals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mission statements (for team)</td>
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<tr>
<td></td>
<td></td>
<td>description of faculty goal(s)</td>
</tr>
<tr>
<td></td>
<td>Personal</td>
<td>Personal reason(s) for joining project</td>
</tr>
<tr>
<td>Academic</td>
<td>Content</td>
<td>Topics covered</td>
</tr>
<tr>
<td></td>
<td></td>
<td>skill level / degree of difficulty</td>
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<tr>
<td></td>
<td></td>
<td>Knowledge and skill building</td>
</tr>
<tr>
<td>Field Work</td>
<td></td>
<td>Field techniques &amp; skills</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical challenges / terrain / weather</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Format / planning</td>
</tr>
<tr>
<td>Tools and Tech</td>
<td>Data Collection</td>
<td>Personal Academic use</td>
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<td></td>
<td></td>
<td>Collaborative Academic use</td>
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<td></td>
<td>Communication</td>
<td>Collaborative Approaches</td>
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<td></td>
<td></td>
<td>Factor affecting when/how utilized</td>
</tr>
<tr>
<td></td>
<td>Tech Ideas</td>
<td>Understanding of how tech works</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ideas &amp; suggestions for future use</td>
</tr>
<tr>
<td>Social</td>
<td>Individual</td>
<td>Social identity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disability Identity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inclusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exclusion</td>
</tr>
<tr>
<td>Teams &amp; Partners</td>
<td>Communication</td>
<td>Communication</td>
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<tr>
<td></td>
<td></td>
<td>Collaboration</td>
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<tr>
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<td>Team Identity</td>
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<td></td>
<td></td>
<td>Inclusion</td>
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<td></td>
<td></td>
<td>Exclusion</td>
</tr>
<tr>
<td>Faculty-Student</td>
<td>Communication</td>
<td>Communication</td>
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<tr>
<td></td>
<td></td>
<td>Inclusion</td>
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<td>Exclusion</td>
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<tr>
<td>Whole Group</td>
<td>Interaction</td>
<td>Interaction</td>
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<td>Segregation</td>
</tr>
</tbody>
</table>
Table 3.3. Qualitative topical categories related to experiences outside of the project from interview data.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-Category</th>
<th>Significant Descriptive Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data related to experiences</td>
<td>Course content</td>
<td>Topics covered</td>
</tr>
<tr>
<td>outside of the project</td>
<td></td>
<td>Relevance to current project</td>
</tr>
<tr>
<td>Academic Background</td>
<td>Course selection</td>
<td>Degree Stage / academic track</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Size of Institution / # courses offered</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exclusionary practices</td>
</tr>
<tr>
<td>Field Work</td>
<td>Physical requirements / challenges</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field techniques &amp; skills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Few/No field work experience</td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td>College / university</td>
<td>Personal social identity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolation/exclusion</td>
</tr>
<tr>
<td></td>
<td>General Public</td>
<td>Negative/Patronizing interactions</td>
</tr>
</tbody>
</table>

The contents of each Sub-Category were then examined for data relating to academic and social engagement, which are presented in Chapter 4. After categorizing, the data were examined for emergent themes relevant to engagement that cross-cut or unite data across categories, discussed in Chapter 5.

3.6.4 Credibility.

The credibility of the results of the both the quantitative video analysis and the social presence survey items are strengthened by comparing the results field observations and with participant’s accounts of the learning exercises conveyed in the end-of-week interviews. Qualitative results also gain credibility through the triangulation of distinct data sources: interview, observation, and open-response survey questions. The comparison of data from each focus group from the second year also provides an extra source of credibility for the findings relating to collaborative teamwork, as the accounts of an event given by team members in one interview can be compared with the accounts of the same event given by team members interviewed in the other focus group.
3.7 Validity, Reliability and Trustworthiness

3.7.1 STROBE protocol validity and reliability.

The STROBE observation protocol has been verified by its creators in two ways (O’Malley et al., 2003). The first is the method of known-groups, which applies the protocol to two different classes that are designed to have different levels of engagement and examines how well the observation results reflect the expected differences in engagement. The second part of the validation compared results from the observation protocol with data from a nine item self-report completed by the students who were being observed. A $t$-test was used to compare group mean scores of the self-report and the results of the STROBE observations.

Reliability testing for the STROBE protocol in the literature has primarily centered around observer reliability. O’Malley et al. (2003) report that simultaneous observations by pairs of observers were in agreement 84% of the time as to how they classified observed behaviors. Average kappa coefficients fell between 0.67 and 1.0. This good agreement between observers shows that the classification scheme is straightforward and easy to understand.

For this study, observer reliability was established based on a second geoscience education professional analyzing 75 minutes of footage after being trained in the use of the observation protocol. Engagement classifications between the primary researcher and the second reviewer were in agreement 90% of the time. Agreement on observations marked as Academic engagement was 100%. This is considered to be excellent agreement and evidence of the trustworthiness of the rest of the video analysis undertaken for this research.

An important aspect of the STROBE method that has not been tested is the how well the limited number of observations accurately reflect overall engagement over a whole class period (or in this case, over the entire time documented on video), and how much the timing of the
observations may influence the results. As part of the video analysis for this research, one video segment was analyzed in two alternative ways; by logging observations for every 20 seconds of video, and by setting a timer and choosing observations at set intervals rather than at the observer’s discretion. The results of this validation are presented in Section 4.1.4.

The STROBE observation protocol as implemented for this research raises several potential concerns regarding validity. Firstly, the protocol was used in a setting far outside of the setting it was designed for. Secondly, the development of additional categories to better suit the objectives of this study has not been validated. However, a check of inter-observer reliability with the modified protocol showed agreement 90% of the time, which demonstrates the consistency with which the additional categorizations can be applied to observations.

3.7.2 Survey Instrument validity and reliability.

Validation procedures for the Sociability Scale are outlined in detail in Kreijns et al. (2007). The survey was determined to have strong internal consistency with a Cronbach’s α of 0.92. The instrument has been validated by applying a Pearson bi-variate correlation analysis to aggregate scores on each item on the survey with other previously developed and well-validated surveys on other aspects of collaborative digital learning environments. (Kreijns et al., 2007). The two open-response survey items were created by the researcher and have not been verified as data collection instruments.

3.7.3 Qualitative Data Trustworthiness.

Qualitative analysis by its nature has some degree of subjectivity. While inter-rater reliability was established for the final coding scheme, there is nothing to say the biases of the researcher did not in some way influence the development of categories and themes. The results of this study are not generalizable due to the small number of participants. The trustworthiness of the
qualitative analysis was established by inter-rater agreement, consultation with other researchers on the project, and the use of multiple sources of qualitative data. Once a coding structure was established (Table 3.2 & 3.3), inter-rater reliability was established by an independent reviewer who coded half of a focus group interview from the second year. The agreement between the researcher and the independent reviewer was 87% at the Category level, 80% at the sub-category level, and 74% at the level of specific descriptive codes displayed in Tables 3.2 and 3.3., which is within the acceptable range to establish trustworthiness.
4. Results

Academic and social engagement in technology-based approaches to field learning were analyzed using the mixed-method approach outlined in Chapter 3. This chapter presents the results of the study. The first section presents the quantitative results of applying the modified STROBE observation protocol to video footage paired with relevant material from video transcripts. Next, the results of the social presence survey are presented, including the quantitative items and the results of the open-response prompts. Finally, the results of a qualitative analysis of interview and observation data collected over both years of the GEOPATH project is presented.

Participants were assigned letter and number designations, which are used as identifiers throughout the results and discussion chapters (Table 4.1). The letter corresponds to the collaborative teams students were assigned to for the duration of the second-year field trip.

Table 4.1. The participant identifiers used in this chapter grouped by team and cohort. See Section 3.3 for details regarding cohorts and participant selection.

| Collaborative groups for the second-year field trip |
|--------------------------------|--------------------------------|--------------------------------|
| Team A                           | Team B                           | Team C                           |
| SWD | SWoD | SWD | SWoD | SWD | SWoD |
| A1  | A2   | B1  | B2   | C1  | C2   |
| A3  | A4   | B3  | B4   | C3  | C4   |

4.1 Results of Video Analysis of Engagement

The modified STROBE observation protocol described in section 3.6.1 was used to obtain quantitative measurements of the time spent engaged in various activities in the field during the second-year field trip. Please refer to Table 3.1 for descriptions of engagement categories. Following a summary of the cumulative analysis results for Direct and Remote
participants, results of the analysis are broken out into four sections. First, the results for each individual participating in field work through remote collaboration are presented. Second, a comparison of engagement levels for two students who participated in field work with both partial direct access and remote access. And finally, the results of a validity check of the STROBE observation protocol are described.

4.1.1 Cumulative results of the STROBE video analysis.

The results of the cumulative analysis of Direct (n=5) and Remote (n=4) participants are illustrated in Figure 4.1. On average, roughly half (52%) of the time students spent during the field exercise was dedicated to academic activities, and 11% was spent on social interactions. Participants were engaged with technology-management and/or troubleshooting 12% of the time. For approximately one quarter (24%) of the time, activity was classified as Disengaged. This is a broad category that includes things such as walking (without outward evidence of any type of engagement such as discussion with field partners), putting on rain gear, self-care issues etc. Disengagement also includes daydreaming or wandering off from the site of the learning exercise. The analysis shows that on average, 47% of the time spent during the remote collaborative exercise was spent on academic activities, and another 16% were spent engaged in social activities. 20% of the time was spent working on troubleshooting or technical problem shooting. Participants using remote collaboration were disengaged 17% of the time.

It is important to note that individual results vary widely for both groups. The largest standard variation for the remote group is in the Disengaged category, $\sigma=19$. The standard deviation for Academic Engagement is large for both groups; $\sigma=12$ for the direct access group and $\sigma=16$ for the remote group. See Section 4.1.2 for a breakdown of individual results for Remote participants.
Figure 4.1. Pie charts illustrating the mean results of a video analysis of engagement for students participating directly (n=5), and students participating remotely (n=4) in field learning exercises. Percentages shown are the mean for each category, with standard deviation listed in parenthesis.

4.1.2 Individual and Team Engagement for Remote Participants.

A total of four Remote students were analyzed using the STROBE observation protocol (Figure 4.2). These students were members of Teams A and B. Two more students, part of Team C, also participated through remote collaboration at with their teammates during the same exercise but due to a camera failure, there was not enough video footage for a meaningful analysis with the observation protocol. However, observational data from the field and a brief transcript helps to fill in some of the details for Team C.

For members of Team C, the transcript of the brief segment that was recorded reveals that there was a great deal of confusion amongst team mates, and difficulty in using the remote communication interfaces. Group cohesion was low, and C1 and C2 frequently talked over each other and/or gave conflicting directions to C3 over the radio. Because of a lack of video footage, it was not clear if the challenges recorded in the last five minutes of the exercise were
anomalous, or indicative of the entire exercise. However, the focus group interview transcripts reveal a significant level of frustration on the part of the team mate in the field, who felt communication with the remote team was often not effective. With very little video footage, the level of academic engagement that was achieved for this team during the remote exercise is difficult to evaluate.

![Figure 4.2](image.png)

**Figure 4.2.** Results of STROBE analysis for each student using Remote participation for the glacial geology exercise.

For Team A, the percentage of time spent engaged in each category was similar for both students. This aligns with observations and video transcripts which showed a cohesive team – with all members, both in the vehicle as well as in the field, working in concert throughout the exercise. During the end-of-trip focus groups several members of Team A talked about how effectively they worked as a team while using remote collaboration with one student stating:

I felt by the end of the trip we had it down. Like we were good that last day with the glacial [exercise] even though it was maybe an hour or less and it was a brutal location.
Even for that little amount of time I think we really had it in the bag. It worked… it was like a model you could deliver to other schools. (A1, Focus Group, year 2)

The analysis shows A1 engaged in technical/troubleshooting activities 33% of the time, and A2 for 24% of the time. Video footage indicates that A1 took the responsibility for technology troubleshooting. For brief intervals, A1 worked on technology issues while A2 was engaged either academically or socially with team mates in the field, faculty or support staff. A small percentage of disengaged time for Team A was the result of self-care issues that arose during a pause for medication.

The results for the two remote members of Team B were substantially different, both from each other and from the results of Team A. Student B1 showed the highest amount of academic engagement of all the remote students, with 72% of time spent on academic activities. On the other hand, student B2 showed the least amount of academic engagement, with only 31% of the total time of the activity spent on academic activities. Student B1 worked closely with partners in the field, while B2 was primarily a passive participant in academic activities.

Social engagement for the remote partners of Team B was low compared to Team A. The video transcript shows much of the social interaction that took place in Team B was not between B1 and B2, even though they were sitting next to each other in a vehicle. For B1, social engagement was divided between attempted interactions with B2 and successful interactions remotely with B3 and B4 out in the field. When attempts at social interaction with B2 were rebuffed, B1 would immediately shift back to academic activities, often with B2 watching passively or disengaged entirely. Social engagement recorded on camera for B2 was primarily with faculty and staff outside of the camera’s field of view. B2 exited the van on several occasions and can be seen walking towards the vehicle where students from Team C were
working. Because B2’s activities outside the van were not recorded, time spent outside the van was classified as Disengaged.

For both Teams A and B, a review of the video footage shows signs of disengagement increasing with the length of time between communication with their partners in the field. For B1, almost all the time categorized as disengaged occurred when waiting on field partners to respond to inquiries. The high winds made communication difficult at times, and a response from the field team often required a move to a more sheltered location or waiting out the wind. A comparison of video footage also seems to indicate the connection for both the wireless devices and the hand radios were less reliable for Team B than for Team A, which may have been a result of the location in which each of the vehicles were parked. In any case, during the lags in communication, B1 would initially work on academic tasks such as recording audio notes about the data being sent from the team or examining rock samples delivered by faculty. But on longer waits, B1’s attention would drift into the disengaged category. Video footage indicates that B2 was somewhat disengaged from the activity from the start, and the detachment only worsened as the exercise progressed. Attempts by B1 to bring B2 into a conversation with the away team or discuss an observation or rock sample were often met with apathy or ignored entirely.

Video also shows Teams A and B differ in the working dynamic that developed during the exercise between direct and remote team mates. While both remote participants of Team A actively engaged in academic discussions of the data sent from the field, they were content to let the field team take the lead on decisions regarding what to examine and what photos or videos to send. On the other hand, the highly engaged remote participant on Team B was clearly in charge of orchestrating field activities by requesting photos and videos, asking questions that guided data collection and explaining to the field team what to look for and why.
4.1.3 Comparison of Partial Access vs. Remote Participation.

For two students, A1 and A2, video footage from two different days were used to compare their experiences of participating in field work with partial site access or remote participation (Figure 4.3). In both cases, these students had limited access to the field site. During the mapping exercise at Recess, these students were limited to outcrops directly along the dirt road through the field site. A1 was physically able to directly interact with the outcrops and use grassy slopes to access upper portions of several outcrops. A2 was constrained to working from the road as the small ditch on either side of the road prevented direct contact with the outcrop from a wheelchair. Samples were delivered to A2 for inspection by A1 and faculty. During the remote collaboration exercise at Renvyle Point, A1 and A2 never saw the field site in person, but instead participated remotely with their team mates through the use of communication apps on their tablets and hand radios. Rock samples were delivered by faculty intermittently during the exercise, and by team members at the conclusion of their time in the field.

As illustrated in Figure 4.3, the results of the engagement analysis for A1 and A2 were significantly different, even though they were working as a team at both locations. For A1, being in the field, even with partial access, was significantly more engaging academically with 82% of the time spent engaged in academic activity compared to 40% during remote collaboration. As illustrated in Figure 4.1, 82% is far above the mean for students participating directly with full access in the field.

The comparison of engagement for A2, on the other hand, shows a quite a different result. The percentage of time spent in academic activity was very similar between partial direct site access and remote access, with only a six percent difference. Concurrently, social
engagement increased by nine percent for A2 when using remote collaboration. The largest difference between partial direct access and remote access for A2 was in the time spent disengaged; 22% for partial direct access and 3% for remote access. Due to the nature of A2’s disability, great care must be exercised in avoiding rain or temperature fluctuations, and an examination of the time marked as disengaged shows that activities relating to self-care took up most of the time spent disengaged from direct field activities. On the day A2 was being videotaped, pop-up rain showers alternating with sunshine required a significant amount of time to layer on or take off rain protection, as well as a few retreats to shelter when the rain was coming down hard. In addition, time was needed to accomplish the slow task of moving a wheelchair from one location along the outcrop to the next down the dirt/mud/gravel track.

Figure 4.3 Comparison of time spent engaged in various aspects of partial field access and remote access for two students using different approaches to participation on different days.
4.1.4 New Validation of the STROBE Observation Protocol.

The STROBE observation protocol was developed for use in live classroom settings to quantify academic engagement. In this study, the application of the protocol to video footage provided an opportunity to check the validity of the STROBE method, which uses short flashes of observation, to quantify engagement. When using an approach that by design only documents activity for 13.3% of the total time of an exercise, it begs the question of how well this approach actually captures the overall activity of the participants throughout the entire exercise. For the original verification reported by O’Malley al. (2003), a self-report instrument was administered to students, and mean values of the STROBE protocol and the self-report were compared favorably. However, this does not entirely answer the question of how well the protocol captures the overall engagement time for the duration of an exercise.

After the STROBE observations were documented for this study, a 40-minute video segment was chosen to re-assess in two ways. First an alternative sampling interval was used by setting up a timer to control when observations were made. The same number of observations were made as in the original analysis but by using the timer, control of when the four observations were made within each cycle is not influenced by the observer. Second, a continuous sampling interval documented an observation for every ten seconds of video. The application of the protocol to video allows for a verification of the effectiveness of the protocol’s sampling method, and how an observer’s choice of when to make each observation within each cycle may influence the results. The results are shown in Table 4.2.

The results of the verification show that the original STROBE observation protocol, the timed observation interval and the continuous interval produce similar results. The original sampling method outlined in the STROBE protocol produced a value of 40% for time spent in
academic activities, while the fixed-interval observations produced a value of 45% and continuous observations produced a value of 44%. A difference of four to five percent seems to be an acceptable result in terms of the ability of the sampling protocol to approximate total engagement.

**Table 4.1. STROBE Observation Protocol Verification Results.** Values shown are for one student using remote collaboration to participate in field work and indicate the percent out of the total number of observations that fall into each category. The STROBE observation protocol calls for four observations to be made at any time within each 5-minute cycle.

<table>
<thead>
<tr>
<th>Category</th>
<th>Original STROBE analysis</th>
<th>Timed Observations</th>
<th>Difference from original analysis</th>
<th>Continuous observations</th>
<th>Difference from original analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic</td>
<td>40%</td>
<td>45%</td>
<td>+5</td>
<td>44%</td>
<td>+4</td>
</tr>
<tr>
<td>Social</td>
<td>24%</td>
<td>27%</td>
<td>+3</td>
<td>23%</td>
<td>-1</td>
</tr>
<tr>
<td>Technical</td>
<td>33%</td>
<td>21%</td>
<td>-8</td>
<td>22%</td>
<td>-11</td>
</tr>
<tr>
<td>Disengaged</td>
<td>3%</td>
<td>7%</td>
<td>+4</td>
<td>11%</td>
<td>+8</td>
</tr>
</tbody>
</table>

The original STROBE protocol was only designed to quantify academic engagement and disengagement. The development of other categories is unique to this research. The largest difference between the sampling interval of the protocol and continuous observations were in the Technical category, with an 11% difference, and the Disengaged with an 8% difference. It is unclear why the protocol did so well with the academic and social categories and less well measuring technical and disengaged categories.

**4.2 Results of Social Presence Survey**

**4.2.1 Quantitative survey results.**

To quantify the ability of remote collaboration to create an environment where participants can feel socially invested in the activities of their group through technology, a modified version of the social presence survey from Kreijns et al (2007), was administered to all participants (n=11) at the end of the second-year field trip (see Section 3.5.2 for description of the instrument). The results are shown in Figure 4.4.
Figure 4.4. The results of the quantitative Social Presence Survey. The bottom bar for each item (in green) shows the percent of positive responses. The middle bar (in gray) shows the percent of neutral responses. The top bar (in orange) shows the percent of negative responses.

Eight of the nine items on the survey had more than 70% positive response, indicating that for the most part students felt that synchronous remote collaboration created a learning environment that allowed for social presence. The item that had the weakest positive response was Item #6, *This approach enables me to identify myself with the team*, which had a 55%
positive response and a 36% neutral response. The strongest agreement was on item #5, *This approach enables me to develop a good working relationship with my team*, with 91% positive responses. When comparing the most and least agreed upon statements, it shows an interesting divide between academic and social engagement when using this technique. While there was strong agreement that remote collaboration enabled users to develop good working relationships with teammates, there was not strong agreement that the approach cultivated an environment where users feel they can identify socially as members of the team.

### 4.2.2 Qualitative Survey Results.

Two open-ended questions were administered with the Social Presence Survey (see Appendix E). The focused nature of the questions as well as the time constraints that participants were under when completing the surveys resulted in concise responses of what students felt were important influences on social engagement. While the prompts directed the students to focus on the things that helped or hindered social inclusion while using remote collaboration (either synchronous or asynchronous), the topics in their responses are broader in scope. Responses focused on the use and/or function of the technology, social climate, and the impacts of remote collaboration on the learning experience.

**Technology.**

The technology itself is a topic focus for many responses. Several respondents express the importance of having hand radios as an alternative means of communication. Students praised the ability to share live videos and photos as a means of both improving social inclusion and enhancing learning. When technology was not functioning as desired and students could not communicate with their team mates for prolonged periods, the remote students reported feeling isolated and the students in the field reported feeling as if they were letting down their remote
teammates. One student took the technology glitches in stride and reported that he/she only felt socially isolated when team members chose not to utilize the communication options when they were available. This student intimated that the lack of communication may have been a choice made by their team mates, but also stated that poor communication from faculty influenced the effectiveness of communication between team mates.

**Social Climate.**

A number of responses indicated that remote collaboration enabled participants to successfully work together with their teammates through the use of technology. The following statements illustrate how remote collaboration promoted social inclusion (survey responses were anonymous):

“As a team we had to work so closely together that you needed to respect each other for anything to work.”

“This approach … made you focus on each other's strengths and weaknesses so I think you got to know each other on a deeper level.”

While many of the responses indicate that the remote collaboration technique itself promoted inclusion, one student did indicate it was sometimes difficult to ask questions or speak to teammates. It is unclear if this statement is referring to social or technical difficulties. One respondent voiced concerns about the broader social dynamic outside of educational activities, and the prompt about social inclusion produced the following statement: “I think a weird dynamic began to emerge with van/mealtime table seating like midway through the study that is rooted in some unpleasant subconscious biases (Anonymous, Survey, year 2)”. This statement encouraged the researcher to analyze interview and observation data for corroborating evidence
of biased behavior, which could substantially impact overall feelings of social inclusion (see 4.3.2, Social Topics During the Project).

Students on both ends of the remote collaboration reported that having a partner physically with them was important. Survey responses indicate that being physically isolated on either end of the remote collaboration would greatly diminish feelings of inclusion. One survey response also suggested that academic outcomes would suffer if a student were working in a location physically isolated from the rest of the team, which connects the theme of social groupings to academic impacts.

*Academic impacts.*

The positive academic impacts of remote collaboration were also pointed out in survey responses. Anonymous Survey responses included phrases such as *productive member* and *active participant* from students who stated they participated remotely. Students who were in the field during remote collaboration remarked that their remote partners often helped them better understand geologic features, and that during the process of reviewing photos with teammates, they would often notice something that was not immediately apparent in the field. One student explained that the process of verbally explaining an outcrop to remote partners increased their confidence in their geology knowledge and helped them clarify their own ideas. Another student remarked that the approach “allowed everyone to feel included because everyone had the opportunity to point something out and discuss it (Anonymous, Survey, Year 2)”. The following Survey response illustrates how remote collaboration improved the educational experience for students on both sides of the process:

> Even when the video feed cut out, we still had the walkie talkies to relay information, so we could get information that way. Then a video of what was being explained, along with
the explanation included in the video, helped a lot. I got the gist, and with my different knowledge I asked them to look for things that I thought might be included they didn't notice. This allowed different expertise to get into the field than what was brought by the people there, and allowed different information to be found that otherwise would not. Same thing for when I thought I saw something through [video streaming]; they could verify it or look for it. (Anonymous, Survey, year 2)

The subject of how the academic workload was distributed amongst team members was a minor theme in conflicting responses. When speaking about asynchronous collaboration, one participant noted that it seemed like the SWoD students in the field were only there to document, and that they were supposed to leave the interpretation to their SWD team mates. Others commented that they appreciated how the approach allowed each person on a team to contribute academically in meaningful ways based on their unique geology skillsets and not their physical abilities.

4.3. Results of Qualitative Data Analysis.

Qualitative data analysis resulted in an organization scheme for coded data into Major Categories, Categories, and sub-categories. Codes were grouped into two major categories: data related to experiences before or outside of the GEOPATH project, and data regarding experiences during the project. Separating codes in this way was important to ensure codes related to experiences outside of the GEOPATH project did not influence the themes that may emerge from project-related experiences. A positive benefit of this approach is that it revealed insights about participants’ backgrounds, and how those backgrounds may have impacted their academic and social engagement during the project.
Emotional Tone of Interviews.

While the prompts used in the interviews were similar from year to year, the overall emotional tone of the interviews were significantly different in each year. In the first year full-group interview, the overall tone was positive. Negative comments were minimal, and minor in scope.

In the second-year focus groups the tone of each interview is quite different. For the SWoD cohort, the tone was variable throughout the interview depending on the topic at hand. Criticisms were larger in scope but discussed in firm yet controlled tones. Participants in the SWoD interview generally stay on topic and are, for the most part, re-directed with little effort when conversations go too far afield from the original topic of the prompt.

For the SWD cohort however, the tone of the focus group at the end of the second-year field trip was strongly negative throughout the interview. Passions ran high and often diverted the conversation away from the topics of the prompts. Attempts at re-directing participants back to the original prompts were mostly unsuccessful, and sometimes met with significant resistance. Some students acknowledged the negative tone and while standing by the substance of their comments, offered apologies to the facilitators for the overall tone at the conclusion of the interview. These differences in tone are not immediately apparent in the coded and categorized data but constitute a meaningful piece of qualitative data in and of itself.

4.3.1 Experiences Outside of the Current Project.

In the qualitative data collected during the GEOPATH project, students shared a great deal about their academic and social experiences prior to or outside of the project. Codes related to outside experiences were grouped into two major categories. Academic Background includes the topics including course content, factors influencing course selection, and prior field work.
Social Experiences include codes relating to social interactions at participant’s home college or university and with the general public.

*Academic background.*

When speaking about their academic backgrounds, students described previous course content, the factors that influenced the number and type of geoscience courses they had taken, and their prior experiences with field work. Participants had a diverse range of academic backgrounds in geology, and each one came from a different college or university. When the first field trip took place, some students had only taken one or two introductory level geoscience courses. By the time the second field trip took place, many had taken more geology courses, and some students had completed their undergraduate degrees.

*Course Selection.*

During the interviews participants often made statements about their point along a geoscience degree track. Many of these comments were made in reference to feeling either academically prepared or unprepared for the academic exercises during the project. Students early in their degree progress had not had a chance to take many geoscience courses, and students from small programs were limited by the variety and schedule of courses offered. Some limitations in course selection were described as Exclusionary Practices. One member of the SWD cohort explained how these barriers impacted course selection:

> What a lot of us are saying is because we have a disability, for some of us that might have changed our educational background or track of courses… There have been courses that I haven’t been able to take; and I’ve been told because there’s one big field experience, I can’t take this course. I can do an independent study, but they weren’t going to let me take the course; which I decided not to fight, which I could have legally; because I would
rather focus my resources elsewhere so far into the semester. And so we have to make these choices. We have these different backgrounds in geoscience often because of our disability. (A1, Focus Group, year 2)

Some discussed how this systematic exclusion drove them to change degree tracks all together rather than try to work around the numerous barriers they encountered in geology. Students that changed degrees explained that they moved to a closely related degree track in natural sciences or geography.

*Previous Field Work Experiences.*

Thoughts regarding the physical requirements, types of field skills utilized, and the format of prior field learning activities was often shared with thoughts of how these experiences were (or were not) helpful in preparing for the field experiences of the GEOPATH project. The codes included in this category appear less frequently in data from the first year of the project than in the second year of the project.

While students in the SWoD cohort shared a significant amount of information regarding the topical content, geologic settings and format of previous field work, a comparison of data from the first and second year reveals a notable change in how students in this cohort describe prior field sites. In the second-year interview, some of the SWoD students spontaneously added a retrospective analysis of accessibility when talking about previous field experiences. For example:

The last big field trip I had…was in structural geology; which was actually reasonably accessible as long as you could get into a standard cargo van. Um, we just walked along a bike path and looked at outcrops, didn’t have to climb anything or anything like that. (A4, Focus Group, year 2)
This change in how members of the SWoD cohort describes a field site – both in terms of its format and its accessibility – shows a shift in mindset from the first and second year of the project in terms of how these students thought about issues of inclusion/exclusion for students with disabilities in the field.

While the SWoD cohort discussed the details of previous field experiences, the SWD cohort shared how Exclusionary Practices had prevented them from participating in field work. Students in the SWD cohort shared how they had previously been barred or excused from participation in field activities or given alternative assignments that did not entail field work. Alternative assignments were often completed alone, further adding to the feelings of social exclusion. One student recounted a typical pre-field trip scenario: “At my home university all the field trips are ‘oh, don’t worry, you don’t need to go because you can’t get there; go to the Museum’. It’s always non-inclusive, I’m alone (A2, Group Interview, year 1)”. Participants explained how this lack of field experience put them at a disadvantage to their able-normative peers in all aspects of field learning, from the basic skills of data collection to content knowledge. As one participant explained, when planning field learning opportunities for students with disabilities, “you have to account for that educational background deficit that might, and probably is, present (A1, Focus Group, year 2)”.

Social Background.

Over the course of the project, students provided insights into social interactions at their home college or university, as well as social interactions with the public at large. There were also some notable interactions with individuals in the general public during the project itself (primarily in the first year), which were also organized into this category.
Codes relating to social climate reveal that a number of the participants struggle with social engagement or experience feelings of not belonging at their home institutions. The most remarkable thing about the data coded into this category is that the majority of these codes came from the SWoD cohort – the able-normative students. One student explained, “I’ve always been a bit anti-social because…in my school in [location], there’s all these people who are not, like, anything like me. And I’m always kind of hiding in a shell most of the time (C3, Focus Group, year 2)”. Another student (B3) shared how feeling socially isolated can negatively impact participation in collaborative learning activities because individuals may not feel comfortable sharing their ideas when they don’t feel like part of the social group.

4.3.2 Experiences during the GEOPATH project.

Major categories of data related to experiences inside of the project include Goals, Academic Experience, Social Experience, and Tools and Technology.

**Student Goals.**

The Goals category includes data relating to participants’ stated objectives for applying to the project, objectives for the project itself, and personal/team goals related to a specific activity. In a number of places in the qualitative data, students make statements about what they believe to be the goals of the GEOPATH project. Often accompanying these statements are personal judgements as to how those goals did or did not align with activities during the project. These purpose statements are not explicitly ‘academic’ or ‘social’ in nature. These purpose statements appear in data from both years of the project and become more specific and well defined in the second year. The following is a list of explicit mission statements made by participants during interviews in the second year, with participant identifiers showing who voiced a verbatim or nearly identically-stated goal:
Develop a method of collaborative field work that could be taught and translated to other schools and/or used in other locations (A1, A2, A3, A4, B1, B3, B4)

Test different technologies that could improve access and inclusion in the field (B1, B3, B4)

Inclusion and helping each other (B3, C2)

Make things better for people (A4)

Promoting the inclusion of SWDs in the geosciences (A2)

Better understanding people’s abilities (B2)

Without being prompted by the interviewers to talk about the goals of the project, these project goals and mission statements were voiced with remarkable consistency across team mates, even when team members were separated into different interview groups. The most commonly stated goal, developing a method of collaborative field work that can be exported to other field courses, was voiced by seven students at various points in the qualitative data, including all members of Team A and most members of Team B. A secondary Goal, voiced by members of Team B, focused on testing technology that could improve access and inclusion in the field.

The influence of these student-created goals is evident in the topics and details that members of each team chose to talk about in interviews. Members Team A often shared very specific operational or logistical details regarding the apps, the format, or their Team’s approach, with some students explicitly saying they wanted the details documented to help inform future iterations of remote collaboration. Members of Team B shared Team A’s goal of developing a system that could be implemented by others, but added their own specific goal of testing technologies to improve access and inclusion. Members of Team B were often observed in the
field experimenting with new ways to use the available technologies. In interviews, members of Team B shared very specific technical details about how the technology functioned and ideas for the potential use of specific devices or apps in future technology-based field learning projects.

*Academic Categories within the project.*

The Academic category includes codes relating to course material and learning experiences, and codes regarding knowledge, skill, and confidence building.

*Academic Content.*

The level of difficulty of the learning exercises compared to a participant’s perceived academic skill level and academic background was a topic of discussion in many places in the qualitative data. However, when prompted to explain what they learned about field geology at the end of the second-year field trip, each focus group responded differently, and codes from one focus group rarely coordinated with codes from the other. As a result, many codes are found exclusively linked to just one cohort. There was one cross-cohort, cross-year lesson participants voiced about geology field work: it never goes according to plan.

For SWoDs, the most commonly-utilized descriptive code was *complexity*. Every student in the SWoD cohort spoke at some point about how the complexity of the geologic setting at Recess, the field site where the multi-day field mapping project took place, took them by surprise. Students in the SWoD cohort talked about the geologic aspects of the field site and how the relationships between outcrops were not immediately apparent. It was not until the last day of the field exercise that any of the students realized that the outcrops the SWDs were mapping on the road and the outcrops the SWoD were mapping along the river were structurally related.

There was a significant difference between the two cohorts when asked to describe what they learned about geology field work. While the SWoD cohort spoke about academic content
and learning in the field, the SWD cohort’s responses were far more general and affective in nature. Commonly used descriptive codes for the SWD cohort included patience, communication, and being able to adapt to changes (Focus Group, year 2). Two students in the SWD cohort responded that what they learned about geology in the field is that they are capable of participating in field learning activities.

*Content: Guidance and Information.*

In interviews from both years of the project, some of the less experienced students described struggling with jargon and advanced descriptions of complex geologic problems. In the first year, students felt that for the most part, their concerns about this issue were addressed over the course of the week. In the second year however, students voiced frustration that they were not given sufficient assistance by faculty to understand what they were seeing in the field.

On the first day of the multi-day mapping project in the Recess area, teams were divided in half and worked in pairs at separate locations. The SWDs worked at the ‘Fish Hatchery’; a set of roadcuts along a gravel road, and the SWoDs went on a cross-country ‘Bog Hike’ to view some unique outcrops (see Section 3.4.2 for site descriptions). Many of the students indicated that this field trip was their first experience with metamorphic rocks in the field, but the faculty members who were familiar with the local field area and metamorphic geology were on the Bog Hike with the SWoD cohort. In the SWD focus group, the lack of experts at their field site was described with frustration and sometimes anger, as participants described the concerns about meeting back up with their team mates with nothing useful to share in terms of knowledge, descriptions or data. The following excerpt from the SWD Focus Group illustrates the impact the lack of guidance had on the students at the Fish Hatchery:
When you don’t have an expert with you on site, especially when you’re not familiar with what you’re looking at … it makes the field sites very difficult to interpret… So if you’ve only had basic geo courses or all of your geo courses focus on another area of study that is not, let’s say metamorphic complex, it’s very difficult to understand or digest the information that you’re absorbing and record the important information about those features when you’re not being properly guided in the field… Like, ‘go look.’ That’s not an answer; that is a ‘Hey you should know this already’…and I think it definitely makes it a less-positive field research experience because it’s self-defeating. (A2, Focus Group, year 2)

Students also felt that they were not given sufficient information regarding daily field activities during the second-year field trip, stating that they “weren’t really kept in the loop as much as in Arizona…so we didn’t really know what to expect quite as much (B4, Focus Group, year 2)”.

A number of the students in both cohorts felt that more information regarding activities and specific goals for the day should have been shared prior to leaving for the field each day and would have improved their academic experience. At the field site, communication between faculty and students was also described as insufficient, as one student explained:

I felt that the technology worked really well, and what broke down was the communication… We’d get out of the vans in the morning, and they’d just say, like ‘go’. They wouldn’t tell us what time we should end, where we should be going, what we should be doing… we really needed to know, like, OK, talk to your teams about this…do this…make sure you focus on this area, those kind of things. (A3, Focus Group, year 2)

In several places in the SWD focus group, participants described the importance in having expert guidance available during the learning experience, as in the following excerpt:
The educational aspect for the second day when we had the expert with us, [faculty member’s name], was phenomenal. [Faculty member] was very good at teasing out where we were educationally; the number of courses we may have taken or our general interest. Prodding that knowledge to weed out various observations and identify key features. I think that would have been really helpful and would have gotten all of this negativity out for the first [day]… because that would have been really, really helpful. (A2, Focus Group, year 2)

Content: Knowledge and Skill building.

While the learning outcomes of the GEOPATH project are not the primary focus of this dissertation, qualitative data regarding student’s feelings of building knowledge and skills can provide insight into academic engagement. In the first-year Group Interview, many students expressed a desire to learn all they could while participating in the project because field learning opportunities are limited in availability.

Throughout the qualitative data, many participants compare themselves with others in terms of knowledge. Personal comparisons of an individual to other individuals; and an individual to the group at large; are found throughout data from both years of the project but occur more frequently in data from the second year. The qualitative data as has numerous ‘me vs. them’ comparisons, often framed in an assumption that others were at more of an advantage in terms of knowledge. When discussing experiences where cohorts were working at different locations, statements of the other cohort having more knowledge in terms of background or current site information appears throughout focus group data from both cohorts.

Regardless of their personal academic skill level, students viewed working with team mates at differing academic levels as a beneficial arrangement for knowledge and skill building.
As one student explained, “[f]acilitating that conversation between the person who has more knowledge, and the person who has less knowledge, is very helpful (C1, Focus Group, year 2)”. Participants explained how students with less knowledge learned from those with more, and those with more knowledge appreciated the insights that novices brought to field work with their direct and uncomplicated descriptions of what they saw in the field.

Students did make statements regarding improved knowledge and gained confidence at the end of both field trips, though explicit statements of knowledge building are more prominent in the Group Interview from the first year. Knowledge and skill building statements from the second-year Focus Groups are rarely explicit, but are present to some extent in descriptions of how students describe their academic experiences. One explicit statement of knowledge building from the second year came from a student (C2) who remarked that in taking the pre and post-test, it the increase in the number of question the student was able to answer was evidence of knowledge gained during the week.

*Academic: Field Work.*

This category contains data related to the aspects of field work that make it unique from other academic settings including physical experiences and the format of field learning activities.

*Field Work: Terrain and Accessibility.*

At the earliest stages of the project, participants were informed that not all of the localities would be physically accessible for members of the SWD cohort as one of the primary objectives of the project was to examine ways to overcome environmental barriers through alternative means of participation. Students voiced appreciation for the degree of accessibility of most of the first-year field sites in Arizona, with the notable exception of SP Crater (see
Appendix D). In the second-year field trip in Ireland, students felt that too many of the field localities were inaccessible.

In interviews from both years, the lack of adequate information regarding the physical requirements at some locations was a source of frustration for members of the SWD cohort. In the first year, students shared how the lack of information affected their experience on the Trail of Time at the Grand Canyon. While marked as accessible, it is 4 km in length with no real options for exiting the exercise. Students were observed struggling with the distance, and traded time spent working on the assignment for time spent resting at the few benches along the route.

In the second year, the locality that caused the most frustration in terms of accessibility was the Fish Hatchery, the first field site for the SWD cohort during the Recess mapping project. Faculty were observed frequently referring to the Fish Hatchery as the ‘accessible’ location for the day’s field mapping activities. In their Focus Group Interview, the SWD cohort described their frustration when upon arrival, it was apparent that the outcrops where not physically accessible for most of the SWDs due to a water-filled ditch along the edge of the road and vegetation obscuring the lower sections of the outcrop. Having no familiarity with the geologic region, and little training on technological approaches available to them, students were at a loss as to how to collect the data they needed without the ability to examine the rock up close. Eventually, the more physically able students in the cohort scrambled over to the outcrop to examine it up close and relay information and rock samples back to the others. As with the Trail of Time, part of the frustration at this location appears to relate to how the description of accessibility did not align with the reality in the field.

On the other hand, an ‘inaccessible’ location may provide excellent accessibility in terms of the learning objectives. An example is Slide Rock State Park, the location of the first field
exercise during the Arizona field trip (See Appendix D for site description). On initial
observation, the personal impression of the researcher in terms of accessibility was negative –
the very feature the park was named for was located in a canyon down a steep flight of stairs and
inaccessible to most of the SWD cohort. However, the focus of the exercise was a stratigraphic
study of the upper portion of the canyon, which was some distance away on either side but was
clearly visible to all participants from a paved walkway. Observation and interview data indicate
participants in both cohorts had a positive experience at Slide Rock because the geologic features
relevant to the exercise were (in a visual sense) equally accessible for everyone.

Field Work: Physical Challenges and Accomplishments.

Data organized into this section include descriptive codes such as physical
access/barriers, physical inclusion/exclusion and physical accomplishments. At the start of the
first-year field trip, students were asked what they were concerned about for the upcoming week.
Students in both cohorts voiced concerns that they would not be able to do what was asked of
them in terms of physical endurance. Members of the SWD cohort, most of whom had never
attempted field work, explained that they had no idea what to expect. One member of the SWoD
cohort said they felt a responsibility to uphold their roles as the more mobile field partners and
was not sure what to expect in terms of the terrain or distances they would be asked to cover. For
members of the SWoD cohort, the most physically challenging activity was an optional hike up a
steep-sided cinder cone volcano during the first year of the project. It is interesting to note that
during and after the hike, students in the SWoD cohort were observed intentionally presenting an
image of ease and/or physical normalcy to the faculty, even when admitting to other students
(and grad students) that they were struggling.
The formats of the first and second year field trips were different, and students in the SWD cohort felt they were given more personal choice as to the level of physical participation during the first year. A member of the SWD cohort explained that in terms of inclusion: “[t]he best part was all the faculty saying, ‘do it if you wanna do it, try if you wanna try, but…you know you better than anybody’, and that was a lot of motivation (B2, Group Interview, year 1)”. During the multi-day mapping project at Recess in the second year, the SWD cohort were kept together in a relatively small geographic space primarily for logistical reasons. However, the justifications were not well-explained to the students, who expressed frustration at being confined to a small area of the field site and not being allowed to venture off the road if they were physically able to do so:

Physically, I feel like I did a lot more in Arizona. I feel like I was able to get places and do things… especially that Grand Canyon [walk]. You know what I mean? That was a huge accomplishment. Here, I stood on the side of the road. (B2, Focus Group, year 2)

The frustration was voiced even by students who could not have left the road under any circumstance, as illustrated in the following interview excerpt from the SWD focus group at the end of the second-year field trip:

Having that option to go into the bog, obviously for someone like me [a wheelchair user] or [another student who uses an assistive device], that’s not really going to work out, right? But for some people that can actually physically go and give it a shot, the shot should be there! (A2, Focus Group, year 2)

In contrast, students explained that in terms of physical engagement, many of the locations for first-year field trip in Arizona took place in locations with a range of accessibility, and students could make their own decisions as to what parts of the field site to explore.
In interviews, each member of the SWD cohort recounted a different physical challenge they felt provided a sense of personal accomplishment. For two members of the SWD cohort, it was participating in the volcano hike at SP Crater during the first field trip; one making it half way up and the other making it all the way up with significant difficulty. For another, the big physical achievement was the completion of the Trail of Time at the Grand Canyon, which was significantly farther than the student had attempted to walk since becoming partially disabled. Although this resulted in being physically unable to participate in much of the following day’s activities, the student voiced pride and a sense of accomplishment in completing the exercise. For a student who is a powerchair user, the notable physical accomplishment was getting from one outcrop to the next down the mud and gravel track at the Recess field site in Ireland. The muddy tires on the chair became a source of pride and the student later remarked:

I was cold, and I was wet, and was like, I need to get to the end of this road. I always have low expectations of my ability to participate physically, so I was very happy when I made it to the end of that road because I felt like I kicked ass! (A2, Focus Group, year 2)

The qualitative data indicates that all students had an opportunity to push themselves beyond their comfort level physically at some point during the project, and the way in which students recount these physical accomplishments indicate they were clearly memorable events for the participants.

Accessibility topics in field work tend to focus on terrain. But the interviews showed that other physical barriers may exist as well. One student explained how tasks requiring manual dexterity may also present challenges:

I have nerve problems in my hands and like muscular-skeletal issues and there’s no rhyme or reason, it just happens… But when [A2] and I were working together, neither of
us are strong or fast writers, so we had to rely on an audio recording, which was hard when it was windy. (A1, Focus Group, year 2)

When it came to these unexpected issues of accessibility, this student assumed that because the GEOPATH project focused on inclusion, faculty members already understood the potential physical barriers to participation in the field, and that they could be addressed preemptively. A1 goes on to explain that because students with disabilities rarely have the opportunity to participate in field work, they don’t know what kind of accessibility-related questions to ask. “I wouldn’t have known to tell someone [about the muscular-skeletal issues] unless I was specifically asked. The faculty know the questions to ask us ahead of time, and that would just help the preparedness. (A1, Focus Group, year 2)”

Field Work: Format of learning activities.

Learning activities were structured to make use of synchronous or asynchronous collaborative approaches (see section 3.4 for details of each exercise). In the first-year interview, several participants expressed a preference for the asynchronous structure, explaining that it was the easiest way to incorporate the many diverse ways in which each member conducted field work. In the second year, the majority of students expressed a strong preference for formats that enabled team members to work together on the same task, including many who had voice the opposite preference in the first year.

The daily format of the Recess mapping project was interpreted by many of the students as intentional “segregation by ability (A1, A2, Focus Group, year 2)”. Students in the SWD cohort voiced disappointment that they had to stay on the road, and that their SWoD team mates were not allowed time with them at the road outcrops. This arrangement made members of the SWD cohort feel socially isolated from the other students:
Everyone with disabilities was lumped together in one group; everyone with physically-able bodies in another group. And if the purpose was inclusion, why did you group- why would you segregate based on abilities levels? (A1, Focus Group, year 2)

During the second-year field trip, students felt the strongest sense of team identity and inclusion during the synchronous format used for the Renvyle Point exercise (see section 3.4.2 for location details). At Renvyle Point, SWD team mates were still physically separated from their SWoD team mates, but students explained that the synchronous format that enabled them to work together in real time, which made them feel like everyone was an equal participant in the field activities. The collaborative nature of the exercise was positively compared to the social cohesion students felt in Arizona in the first year:

For the three-day Recess mapping, the two cohorts were completely divided. For that glacial activity [at Renvyle Point], we were looking at the same thing and we were not divided. And that’s mirrored to what we did in Arizona more. (A1, Focus Group, year 2)

Tools and Technology.

The category Tools and Technology includes data specifically related to the use of technology for Data Collection and Communication and was developed from the numerous descriptive codes that dealt specifically with the participants’ uses and opinions of the various technological tools utilized during the project. As part of the coding and categorizing process, a significant amount of data related to technology was coded as app-specific or technical. This data was not included in the development of categories and was passed on to other researchers on the project. The data presented here relates more generally to how the students used technology to enhance their data collection and communication efforts in the field.
Interview data shows that learning new technology came naturally to some students but learning new technology on the fly while also learning geology skills within the context of a field trip was challenging for some. A number of students expressed frustration at the lack of technical training, or that the training they did receive came too late to be useful because they had either taught themselves how to use the technology in question, or already attempted and abandoned its use entirely. Two students continued to use paper field notebooks throughout both years of the project either as a primary or secondary means of documenting data and used the tablets primarily for taking photos. These students relied on their team mates to use the digital data collection tools when necessary.

Students with limited manual dexterity shared how voice-to-text enabled them to take notes in the field, and drawing apps allowed them to sketch with their finger rather than attempting to grasp a pencil. For these students, digital field notebooks enabled them to participate in a way that was not possible with paper field notebooks.

One of the most appreciated features for all students in terms of data collection was the ability to take high-quality photos and videos with the tablets. Photos could be annotated on location by adding notes and sketches. Students shared in interviews how this greatly enhanced their ability to effectively document a field site. It also provided the ability to sketch out potential interpretations on the photos and ask for feedback from other team mates or faculty later.

For the Recess mapping exercise, structural data from all students were combined to build a digital structural map. Students indicated that this collaborative approach to building a structural map of the field site had several positive benefits. First, it greatly aided the student’s understanding of the geology of the area, and how each of the field locations related to each
other. In fact, several students voiced surprise at the results of the collaborative map, because they did not realize that the field site each of the cohorts were documenting (SWDs on the road, SWoDs by the lake) had a structural relationship to each other. The second benefit voiced by the students was that it provided tangible evidence of how everyone’s efforts were contributing to a larger academic product.

The wearable cameras proved to be a versatile tool for data collection and academic engagement. It was an ideal tool for recording notes and ideas about a field location without having to free up their hands. Students using the cameras in this way made short video logs that ranged from a few seconds to several minutes in duration. The hands-free documentation allowed them to point out features, hold up rock samples and record visual data to go with their audio notes. During the first-year field trip in Arizona, students had the option to undertake a challenging hike up the slopes of a cinder cone volcano, and one student remarked later that the footage from the wearable camera provided an opportunity to examine features that were not he noticed in the focus on climbing (B1, Group Interview, year 1).

During the Remote Collaboration exercise at Renvyle Point, remote participants explained how they used the wearable cameras to record audio notes instead of trying to free up screen space and hands to take notes on the tablets while data from photos, videos, hand radios and delivered rock samples were received in rapid succession. Students were observed holding radios closer to the camera to capture incoming audio from their field partners and holding rock samples up to the camera for documentation while they discussed. When asked by an observer if they should be taking notes, one student remarked that “there was so much information coming in at one time it was difficult to communicate with the away team, discuss the information on the feed, while also recording notes (A1, Observation Notes, Year 2)”. Students in two of the three
vans adapted by utilizing video cameras on continuous recording mode as a means of documenting information as it was coming in. Students made a point of voicing observations and ideas aloud, holding radios up to record incoming audio from the field, and holding rock samples up close to the camera lens.

Some students chose to use the wearable cameras as a means of social inclusion by sharing a more personal view of what it was like working at a field site. Cameras used for this purpose were worn on continuous recording mode, so every moment was recorded for team mates, as described in this interview excerpt:

I loved the [cameras] and being able to wear them to walk around… Just getting a sense of the area that you’re in. Because, like, we’re in Ireland and it’s so amazing and the whole point of field work is that you’re going to places you’ve never seen before. And understanding the aura of this place is, like, - even if you’re just staring at some sheep or trees, you’re still getting an idea of the area that you’re in. And that can tell so much, like there are ways you can tell what rock is under certain types of grasses. So you need to see everything, and I think that the [video cameras] really helped with that. (B4, Focus Group, year 2)

*Tools & Tech: Communication.*

The ability to communicate with team mates was important for academic activities as well as social inclusion, especially during exercises where only part of the team would be visiting an outcrop. During the first field trip, the approach for live streaming video was not well developed and only used for a few moments towards the end of the trip, so the bulk of qualitative data regarding digital communication comes from the second year of the project.
One of the more frequently used descriptive codes in this category is conversations. One of the most talked-about aspect of communicating with streaming video was the ability to discuss features in the field in real time with partners in another location. An interview excerpt from the second-year interview shows how impressed the students were with the ability to discuss with their remote partners at the Renvyle beach location:

I really liked that we were taking turns…and [our remote partners] were both communicating with us, like ‘zoom in on this part’ or like, ‘What can you tell me more about the grain size? Give us a scale or something.’ And I thought that was really awesome that we were, like all four of us, really having a conversation. (B4, Focus Group, year 2)

This ability to communicate visual and audio information simultaneously provided the ability for remote participants to make discoveries and contribute to their team’s documentation of the field site. During the exercise at Renvyle Point, a student at the outcrop (C3) observed another group (Team A) working with their remote partners using the streaming video app and remarked at how one of the remote students made an insightful observation about the outcrop through the remote link:

[A2] was pointing out that the rocks were falling off of the cliff side due to erosion due to like the tides and like wind basically. And as soon as I saw it I was like ‘Oh, my god, yeah, he’s right!’ And it was [the remote teammate] that pointed it out; which is, like the definition of being inclusive because he was included. He was able to really see it. (C3, Focus Group, year 2)
Some participants felt they would have made more use of the communication technology if not for conflicting or lack of instruction. One student described an instance where a faculty member told the student not to contact teammates and focus instead on collecting mapping data:

That was my biggest frustration on this trip… this is an inclusive trip and we’re testing technology and we weren’t allowed to use the technology… we weren’t allowed to communicate…it bothers me so much! (B4, Focus Group, year 2)

Students realized the value of remote collaboration and the conversations that resulted in sharing visual information in real time. When live streaming was not an option, students in Team B described how they adapted by recording videos while verbally describing features to their remote partners using hand radios. When team members came back together, all members of the team could watch the footage together to clarify what had been described over the radio. In separate Focus Groups, members of Team B commented on how the process improved the educational experience on both sides of the collaboration:

When the Wi-Fi went down when we were at the glacial till, I videotaped [my remote teammate] and [my field partner] having a conversation… And you know you can hear their conversation about it, but [the remote teammate] couldn’t see what we were talking about. [My field partner] was just trying to describe it in the best way that [s/he] could… I wasn’t really paying attention for a second and then I saw what [s/he] were looking at. So I took the [tablet] and I stuck it up as high as I could, right close to where s/he was looking. I went all around there so that they could see afterwards what they were discussing, while they were discussing it… And [the remote teammate] said that it was super useful, and I felt like it was super useful too. (B3, Focus Group, year 2)
In the above excerpt, the student in the field explains that in working to improve the remote team mate’s experience, it brought the students attention back to the learning activity and prompted more engagement in the discussion. In a separate focus group, a remote team mate also commented on this same event and the educational benefits to the approach:

One thing that worked really great was- I keep going back to this – was they were describing what they were seeing. [The field team] took a video of what they were describing where you could hear the overlaid voice in the background describing what they were seeing… So, you got the gist of it beforehand [over the radio], and you were able to, with your knowledge, ask them to look for certain things and ask them if it looked like this or it looked like this. And then when they got back, they could point out things with the video and at that point, you were able to resynthesize everything together. (B1, Focus Group, year 2)

_Distribution of technology._

There were six wearable cameras available during the second field trip, so decisions had to be made daily as to who had use of the cameras. Sometimes these decisions had an unexpected impact on feelings of social and academic inclusion or exclusion. During the first day of the field mapping project at Recess, all of the wearable cameras were sent with the SWoD cohort due to a logistical mix-up. The message that the SWD cohort took from their lack of technological tools was that their location was unimportant and essentially being used for busywork, as summarized by a student recounting their experience:

It made me really mad … It made it just feel like okay, you guys get this outcrop, while the other group gets the cool outcrop. They have the [video cameras] to look at the cool
outcrop, but we have nothing to show them our outcrop because it doesn’t matter. (A1, Focus Group, year 2)

As an indication of the value students placed on the footage from the wearable cameras, several students in the SWoD cohort spoke about frustration in not being able to “see” the Fish Hatchery location (A4 and C3, Focus Group, year 2), even though the students at that location took photos and collected data on their tablets. For many of the students, the first-person vantage point of the wearable cameras was the next best thing to being there and provided a broader visual context for photos, descriptions and data.

It was brought to the researcher’s attention several days into the second field trip that priority on the use of the wearable cameras, which the researcher was in charge of managing, was by default going to the SWoD cohort. This unequal distribution was immediately rectified. However, based on their Focus Group Interview, the SWD cohort took their shortfall in technology tools as a two-fold issue of exclusion. First, they felt they were being put at a disadvantage in terms of being able to document their field site. Second, some in the SWD cohort believed that they were not provided the wearable cameras because they weren’t working at a location worth documenting in terms of the larger mapping project.

**Social Topics within the project.**

Data coded into this category deal with the social relationships and identities within the project. Participants shared thoughts about their identities within the group, and how those identities may have changed over the course of the project. Students also spoke about the social dynamics of their working groups and the influences on the overall social climate of the project.
Social: Individual Social identity.

In the first year, participants expressed appreciation for the inclusive social climate of the project that allowed them to feel comfortable ‘letting their guard down a bit (C1)’. In the second year, students started off with a familiarity with each other that allowed an even stronger sense of social inclusion. Students felt free to be themselves without judgement from their peers. Students strongly believed that the inclusive social climate improved their academic engagement. Participants explained that when you no longer feel the need to hold back questions and ideas, you are free to participate in academic discussions.

Disability Identity.

‘Disability identity’ was a code used to mark data related to a person’s identity as part of the disabled community, or a judgement passed as to someone’s disability status. At the start of the first-year field trip, participants were just getting to know each other, and it was not always apparent who belonged to which cohort because not all the disabilities were visually obvious. For students with non-apparent disabilities, a great deal of speculation occurred as the nature of their disability. Outward evidence led to some incorrect assumptions from both students and faculty.

The qualitative data also indicate a gray area surrounding what it meant to participants to be ‘disabled’. One student in the SWoD cohort (B4) admitted to not being sure which cohort they were recruited for based on the answers their application. This student did not consider themselves disabled but did explain on the application that they were a Type 1 Diabetic. To further complicate things, this student had recently dislocated a knee which required a brace. While the student had applied as a member of the fully-able cohort, there was still concern about personal safety in remote areas, and these concerns had caused hesitation to participate in field
work in the past. However, the inclusive social environment promoted during the GEOPATH project eased the worry of undertaking field work:

It is really hard to go in the field and carry that much supplies, and if anything goes wrong, like, I’m like, dead. So I thought this was really nice that even though I wasn’t considered, like, a less-abled person, that if I needed to, I could you know, … just join their [the SWD] group. And that was really nice to have. And just like realizing that like everyone is here for you. And the whole time [my partner] was always asking me ‘how are you feeling? Is your blood sugar fine?’ and that was nice… I think this was a really good start to realizing that this is something I can actually do. (B4, Focus Group, year 2)

On the other side of this gray area, some students recruited for the SWD cohort had disabilities that did not impact their physical ability all the time; only during flare-ups. Combined with illnesses and minor injuries on any given day in the field, some of the SWD cohort were equally or more physically able than members of the SWoD cohort. Students in both cohorts took the fluidity between cohorts in stride because as a member of the SWoD cohort explained:

At some point, it doesn’t matter how ‘physically able’ you are cause, I mean I, as the videos will show, I fell in the bog; I slid down a rock and stuff. So you know at some point you know you reach a certain limit where it doesn’t matter how ‘able’ you are, you know you’re just gonna - there’s gonna be a limit to where you can go. (B3, Focus Group, year 2)

Social: Teams and Partners.

Several types of team structures were employed for field work during the course of the project. Two structures were assigned by the researchers; rotating partners and fixed teams of four. A third developed informally which the students refer to as the ‘amorphous group’.
Rotating partners were used throughout the first-year field trip. Students worked in teams of two – one from each cohort – to complete the day’s activities. The next day, partners were re-assigned, so each person had the chance to work with everyone in the other cohort at some point. Several of the students expressed a preference for this format because it gave them a chance to know everyone on the project, and they were able to work with people with diverse geology backgrounds.

All learning exercises in the second field trip, with the exception of the first day at the Cliffs of Kilkee, were completed with the same team members. Some participants appreciated that the permanent team structure allowed the develop a group identity and discover approaches to field learning activities that worked best for their team. However, a minority of students felt that the fixed teams diminished the chances of interacting with everyone on the trip and expressed a preference for non-permanent team structures.

Views were mixed on the idea of the amorphous groups used informally at the Grand Canyon on the first field trip, and at the Cliffs of Kilkee and Fish Hatchery during the Ireland field trip. This arrangement, as described by the students, is a constantly changing roster of team members and group size depending on the task at hand and physical requirements and developed in settings where either no groups were assigned, or a unique collaborative effort was required to overcome barriers to completing an assignment. One example of a location where this format was employed was the Fish Hatchery. Students were formally working within assigned teams of four, with two SWD team members at the Fish Hatchery, and two SWoD team members at another location. With the SWDs working without their SWoD counterparts, some teams were not going to be able to get the data they needed due to physical limitations. Students explained that the amorphous group format was employed so that members of the SWD cohort that were
more physically mobile could assist those who were less mobile. Participants’ views on the effectiveness of this approach are mixed. Some students were very sensitive about their partner working with any other students and viewed it as an ‘abandonment’ of their assigned team mate. Other students appreciated the flexibility in working groups and the community effort that allowed everyone to get the data they needed.

Teams and Partners: Inclusion.

Data coded in this sub-category included data related how team mates created an inclusive team environment. When talking about their use of technology, a number of students described how they modified their behaviors to more inclusive. One student described how they changed their walking pace and style to improve the footage being recorded on the wearable camera for remote team mates:

When I was walking, [A3] was like ‘oh, I’m gonna walk slower so people can see’. And I realized the whole point of me walking with this [camera] is so you’re not just staring at the dirt that I’m walking on necessarily. But let me stop, show the lake that’s right here, and really be able to capture the moment of being there. That was really important. (B4, Focus Group, year 2)

For Team A, an important shift in the way team members operated in the field occurred as a result of the difficult conditions the SWD cohort encountered in documenting the outcrop at the Fish Hatchery during the Recess mapping project. When the team members who were at the Fish Hatchery shared their data and notes, a team mate describes their reaction:

Now that Hatchery outcrop is the only one I haven’t seen in any fashion. And looking back that evening at [my team mate’s] pictures from there it was like, ok, I guess I can see what you are getting at? But it’s just looking at pictures the way they did it there,
because we hadn’t introduced, or we weren’t really using the other apps so much yet, it was like ‘wow – this sucks!’ This is no substitute for actually being there and getting to climb on the outcrop and stuff like that. So that was…(pause)…more of a shock and an unpleasant surprise than I was expecting. And so we were looking at that and I was like, ‘wow – this is…this is unpleasant! I can’t tell this is granite. You’re saying this, this pink stuff in this kinda gritty picture is k-feldspar, and I’ll trust you. I trust you and assume that’s not stained quartz, but I don’t know any better’. (A4, Focus Group, year 2)

This same student goes on to explain how looking at the disappointing results from the Fish Hatchery defined the inclusive approach Team A would take for the remainder of the field trip:

Getting that perspective that I didn’t really have before, on what it is to be in the world of the unfortunate majority of field experiences where there’s no allowance for having a disability, and so you’re just left with this hollow version of a field experience… So from then on I was like, we need to fix this. There’s stuff we can do, and I can put other people’s appreciation and experience with this field site ahead of my getting to look at the 17th recumbent fold today…So it’s getting that perspective and getting to carry that forward into the rest of the trip and the way we act, I thought was a really interesting and a valuable part of this. (A4, Focus Group, year 2)

Defining Roles.

Over the course of the project, participants developed a sense of the roles which members of each cohort were expected to fulfill within the team structure. For much of the project, the role of SWoD participants was primarily described as data-gatherer, and the role of SWDs was described as data-interpreter/synthesizer. However, the assumption of these roles sometimes created frustration for members of both cohorts. Members of the SWoD cohort shared in
interview how they felt their role was sometimes relegated to physical tasks and basic
descriptions, with the role of interpreting data reserved for SWD team members. Some SWoDs
felt this left them without a significant academic contribution to the assignments, and one student
expressed a desire to contribute more than the simply the ability to “hike and take photos (B4,
Focus Group, year 2)”. Conversely, there was an expectation among members of both cohorts
that SWD teammates would be able to contribute knowledge and interpretations to support their
team’s efforts. SWD team mates expressed frustration at their inability to contribute when they
felt their academic background was not sufficient to interpret the data, or opportunities to
contribute were not available.

For some students, these assumed roles (SWoDs = data gatherers, SWDs = knowledge
sources) created sometimes un-realistic expectations for team mates, or personal frustration. A
member of Team C, who was expecting more in terms of data collection from team mates,
explained their perspective in the following excerpt:

…when I got back at the end of the day, they barely said anything to me…and they took
like, one or two [data points]. And then you have the other groups, who seemed much
more organized than ours did, and I felt like I was almost left on the island, kind of.
Because already I’m not that well versed in geology… I mean, they did contribute a bit,
but I felt like I was just, trying to combine everything and I felt overwhelmed. (C3, Focus
Group, year 2)

Observations in the field make it clear that members of Team C struggled with creating a
positive social environment and did not view their time in the field as a collaborative process
where all team mates contribute to both data acquisition and interpretation, but rather as the
execution of isolated tasks based on assumed roles.
When roles were applied in a productive way, each team member had a clear idea of what they could contribute to the learning activity and felt a sense of accomplishment and inclusion when each person’s contributions came together into a finished product. One member of Team A explains how identifying strengths and assigning roles seemed to be academically beneficial:

The division of labor, particularly with app usage and technologies...each member of our team had different areas of expertise, and the way we split up the final mapping project based on what we knew how to do, and our field impressions was really neat to see in action. (A3, Focus Group, year 2)

Social: Faculty.

Both cohorts imparted significant meaning to the time invested in their group by faculty members whom they considered experts in the field, not just in terms of learning (see Section 4.3.2, Academic Content>Guidance & Information) but also in terms of social inclusion. When students felt their questions or unique needs were not being addressed by the faculty who were present, this was not only frustrating from a learning perspective, but also carried social meaning, as described below:

[Y]ou would ask a question and then your question would be answered with another question and then conferred with an ‘I don’t know, you need to go look’, which is extremely difficult when the closest you can get to said outcrop is 10 feet away. (A2, Focus Group, year 2)

This student voiced concerns about the ‘tone deaf’ directive to examine the outcrop personally when a ditch prevented the student from directly accessing the outcrop. This response further reinforced to this student the perception that individuals with disabilities do not belong in
the field, as evidenced by the inclusion of the phrase “geology isn’t really meant for people in wheelchairs (A2, Focus Group, year 2)” in a statement immediately following the above quote.

After the unsatisfactory experience at the Fish Hatchery, observations indicate that the students became increasingly sensitive to any instance of what they interpreted as avoidance or segregation by ability. In conversations with the researcher, students voiced frustration with what they interpreted as a pattern of avoidance by expert faculty at Recess (specifically at the Fish Hatchery) and to a lesser extent at Renvyle Point. Mid-way through the second-year field trip, students were observed discussing the choice of seating arrangements at mealtimes, and how it fit the pattern of exclusion they saw in the field. While faculty sitting apart from students during mealtimes is not unusual on field trips, students in the SWD cohort interpreted as yet another example of avoidance. On the other hand, students spoke highly of faculty that invested both technical knowledge and personal engagement in the field. One student shared how time spent with experts helped overcome occasional feelings of social isolation caused by physical separation from other students during field work and was an “incredibly important (A2, Focus Group, year 2)” aspect of social inclusion.

Social: Whole group.

Interview data from the first year shows a much stronger sense of inclusion in terms of the entire group. Students commented on the feeling that everyone, students and faculty, were working together for a common goal, as described in the excerpt:

A study like this where everyone’s engaging with each other and working with each other and learning from each other – it not only builds inclusion, but it also lets people understand that people with disabilities… are not only capable of doing research
initiatives, but they are capable of contributing to the research community at large. (A2, Group Interview, year 1)

In the second year of the project, with a few notable exceptions, students felt that they had developed a positive social environment with their peers during the second-year field trip. As one student explained in a Focus Group Interview the second year, “[E]veryone in this group is just a bit weird, which is really cool (C3)”. This theme was picked up by another student in the same focus group who added, “[E]veryone is weird, not just in this group, but in the world…and as soon as you accept that…we can all be weird together (B3)”.

The weak point in the social fabric of the group was a result of the consistent separation during the Recess mapping project, which participants explained created social isolation between the two cohorts, with some students using the word “segregated (A1, A2, Focus Group, year 2)” to describe the social situation. The social division was exacerbated by the lack of communication between team members in each cohort. Students explained that they eventually determined that the lack of communication was not always an intentional choice by their teammates, but sometimes a result of conflicting instructions from the faculty (see the previous section on Tools & Tech> Communication), or simply technical issues. Before this issue of communication was discussed amongst the students, a significant social rift had formed between the two cohorts. Yet it is an indicator of the strength of the social structure of the group that they students were able to talk through and resolve this source of social division.

There is near total agreement that students felt the strongest sense of social inclusion during the Renvyle Point exercise, not just among their respective teams, but as a whole group. The collaborative nature of the exercise was compared favorably to the social cohesion students felt in Arizona in the first year:
For the three-day Recess mapping, the two cohorts were completely divided. For that glacial activity (at Renvyle Point), we were looking at the same thing and we were not divided. And that’s mirrored to what we did in Arizona more. (A1, Focus Group, year 2)

The strongly positive views of the Renvyle Point exercise is interesting because the SWDs were not only physically separated from the SWoD cohort, they were also physically separated from each other with pairs of students working in separate vehicles. Students explained that by synchronously participating in field activities, they felt included in the field activity, and more socially in the group as a whole.

**4.4. Summary of Analysis.**

This chapter presented the results of three sources of data that each lend insights into the level of engagement during the GEOPATH project, as well as the potential influences on engagement. First, a video analysis using the STROBE observation protocol provided a quantitative means of evaluating engagement of students using remote collaboration to participate in a field learning activity. Supporting data from transcripts of the videos provide details to support the quantitative analysis. Second, the results of a survey of social presence provided both quantitative and qualitative data to examine the capacity for remote collaboration to promote social inclusion through the use of communication technology. Third, a detailed descriptive analysis of qualitative data from interviews and observations provided a means to explore potential influences on engagement in a complex, real-world application of technology for collaborative geoscience field work. In the next chapter, themes from the results are organized with their respective research questions with a discussion of how the results of this evaluation align to the literature presented in Chapter 2.
5. Discussion

Engagement is a necessary precursor to learning (O’Malley et al., 2003), and is especially important to retain students from traditionally underrepresented groups (Davidson, 1996; Reschly & Christenson, 2006). This study examined engagement for students participating through remote collaboration using video analysis, surveys, and qualitative response analysis. The results fit well within the framework of Social Learning Theory which frames geoscience field work as a learning environment where academic and social engagement are influenced by many of the same things, and also influence each other (Streule & Craig, 2016). This chapter will discuss the address the research questions, discuss the results organized into themes and relate the results to the literature presented in Chapter 2.

5.1 Addressing Research Question #1

Question 1: Does remote collaboration through technology enable academic and social engagement in the field?

5.1.1 Engagement Evidence from video analysis.

The results of the quantitative video analysis indicated that cumulatively, students participating directly in the field spent only slightly more time engaged (52%) in academic activities than students participating in field work virtually through remote collaboration (47%). However, the range of individual results was large in both groups, $\sigma = 12$ for the direct group, and $\sigma = 16$ for the remote group. These highly variable results may simply be the result of differences in personal approaches to field learning, or they may indicate that other un-identified factors influenced individual engagement levels.
One of those factors may be the amount of contextually relevant knowledge each student possessed. A review of the footage from students participating directly in the field suggests that experience level was influencing the degree to which students could effectively collaborate through technology, as novice students in the field struggled to determine what was worth documenting for their team mates. As one participant explained later in an interview, “[I]f you’re out there using the technology… but you don’t know what you’re looking at, then the information is kind of useless at that point (B1, Focus Group, Year 2)”. Another study of a small group (n=7) of geoscience practitioners in the field indicated that experience level plays a significant role in how individuals spend their time in the field with more experienced mappers working methodically and efficiently while novice mappers may wander and be more easily distracted from learning activities (Petcovic, Libarkin, & Baker, 2009).

When comparing social engagement levels across direct field access, partial field access and remote (virtual) access, the results of the STROBE observation protocol provide interesting insights. When viewed cumulatively, the synchronous remote group had higher levels of social engagement than participants working directly in the field with a partner, 16% vs. 11% respectively. Social engagement for each individual in the direct group was nearly identical (σ=2), but for remote participants was more variable (σ=11). The small increase in social engagement for the remote group compared to the direct group may be a result of the ease in which interaction could take place. During the exercise where synchronous remote collaboration was used, team members remained in close proximity to each other - two team members sitting in a vehicle together, working with two team members in the field who stayed in close proximity to each other to better manage communication devices.
The participant with the lowest percentage of time spent socially or academically engaged during the synchronous remote collaboration exercise, B2, also struggled with social interaction when participating directly in the field. The strained social relationship between B2 and B1 was evident from the start of the video of the remote exercise and were related to events prior to the remote collaboration exercise. Observations made earlier in the field trip indicate that B2 approached faculty claiming that in a previous field exercise, B1 “ditched” his/her team to work with a more physically-mobile SWD from another team and felt this was a betrayal of sorts. Ironically, B1 recounted that same event positively in interview, explaining that in working with that other student, the two of them were able to reach more of the outcrop and gather and relay data that helped all of the SWDs who were having difficulty interacting with the outcrop at the location in question. This unresolved misunderstanding of the perceived motivations and social meaning of the actions that took place during the previous exercise illustrates the often-complicated nature of collaborative team dynamics and highlights how social issues can directly impact academic engagement.

In comparing two students who were video recorded participating both directly through partial field access and virtually through remote collaboration, the engagement results for each student are quite different (Section 4.1.3). For Student A1, partial direct access to the field site was substantially more academically engaging that participating remotely, with 82% of the time spent in the field on academic tasks compared to 40% of the time during remote collaboration. Based on Observations, this student was quite driven and focused in the field and was rarely distracted from academic activities. During the remote activity, this student may have been having difficulty adjusting to a hand-off approach to field work. However, A1 was significantly more socially engaged with team mates during remote collaboration with 24% of the time spent
in social interactions compared to 7% when participating directly the field. For Student A2, the difference in both social and academic engagement between direct and remote participation is much smaller (see figure 4.2). For Student A2, the complex physical and weather-related considerations of direct field work produced lower academic engagement levels in the field when compared to team mate A1. The differences in how A1 and A2 spent their time with partial or remote access illustrates the importance of finding the proper fit for students according to their particular needs and learning style.

The amount of disengaged time for direct and remote students may be influenced by two things. First, students in the direct group required time to move between outcrops, deal with rain gear and other such things that are necessary for outdoor field experiences. Secondly, the Remote students had to take in a large amount of information coming in from streaming video, shared photos, and radio discussion, which based on observations and interviews, took more focused attention to adequately manage. Further, this difference could be due in part to the length of video footage analyzed for each group, with the footage of the direct students twice as long as the footage of the remote students. It may be that if the remote activity were longer, the percentage of disengaged time might increase.

5.1.2 Engagement Evidence in Survey Results.

Social presence describes the capacity to project one’s own personality into a digital environment to interact with others in a meaningful way (Garrison et al., 1999; Warburton, 2009). It therefore a necessary component of any virtual learning environment that aims to promote engagement. The social presence survey is not a direct measurement of social engagement, but instead measures the capacity for remote collaboration to create a social environment conducive to engagement. The strongly positive results of the majority of
quantitative items on the survey (section 4.2.1) indicate a learning environment where social engagement is clearly possible provided it is used within a larger frame of social inclusion and support.

The qualitative responses to the open-response items on the social presence survey provided clear evidence of academic engagement through synchronous remote collaboration. Respondents described in detail how academic activities were carried out through active engagement from all team members, both those in the field and those participating remotely (see excerpt on p. 76 for an excellent example). The open-response items provide evidence of social engagement as students described social interactions and “getting to know each other on a deeper level (Section 4.2.2, p.73)” through the use of remote collaboration.

The results of the survey also indicated that the technology-based approach to collaborative field work provided a highly positive affective experience for most participants. Responses to the qualitative survey items indicated that students valued the ability to share photos and videos as a means of enhancing social engagement in both synchronous and asynchronous remote collaboration. The wearable cameras provided a means to convey additional affective qualities of the field site to remote teammates such as the “aura of a place (p.94)” including weather, terrain, scenic views and social interactions (Section 4.3.2, Tools&Tech>Data Collection). This vicarious means of exploring a field site was especially valuable in terms of social bonding with both teammates and the larger group as a whole.

**5.1.3 Engagement Evidence from Interview Data.**

There is an important difference between the more academically focused responses of the SWoD cohort and the more general and affective responses from the SWD cohort when asked what was learned about geology field work at the end of the second-year field trip. The SWoD
cohort talked in depth about the academic content, format, and field experience, clearly indicating a significant level of academic engagement was achieved in the field. The SWD’s responses to the same prompt were primarily non-academic in nature, stating that they learned the need for patience, adaptability, and communication. These responses highlight how different the academic experiences were for the two cohorts in terms of academic engagement. And while this disparity may simply reflect the experimental nature of the project itself, these results also emphasize the need to further examine the factors that influence engagement in field learning environments, especially as they pertain to new or unconventional approaches to participation.

5.2 Addressing Research Question #2.

Question 2: What are the factors that influence academic and social engagement when incorporating remote collaboration in field learning activities?

5.2.1 Theme 1: Academic Insecurity.

Participants described a wide range of academic backgrounds and experiences, from novice to advanced. For students with limited geoscience backgrounds, this laid the groundwork for the emergence of academic insecurity, defined here as the feeling that one is not prepared to succeed in a given learning exercise or activity. The theme of academic insecurity was prevalent in both cohorts. This theme diminishes over the course of the 1st year field trip but is still present in a small degree during the end-of-week interview. The theme strengthens in the second year of the project and remains significant throughout the week. In a few cases, this insecurity appears to be rooted in part in personal self-doubt (in particular with C3 and B2), but in a number of cases it appears to be based on academic backgrounds with little relevance to the learning activities undertaken during the project.
Prior coursework of the participants was influenced by three things: (1) their point along a degree track, (2) the availability of courses at their home institutions, and (3) in some cases for the students with disabilities, exclusionary and/or discriminatory practices (Section 4.3.1, Academic Background). The discriminatory experiences of the participants of this study indicate that the pervasive inequity and culture of exclusion in STEM fields (Jenson et al., 2011; A. Lee, 2011) the geosciences (Atchison & Libarkin, 2016; Hall & Healey, 2005; Hall et al., 2002; Healey et al., 2002) continue to be a barrier for individuals with disabilities. This study contributes knowledge as to how these barriers at the institutional level impact educational opportunities for geoscience students with disabilities and how the lack of opportunity can have a direct impact on the knowledge and skills these students have access to.

The literature describes how novice learners often have significant difficulty with mapping and spatial understanding and may require extra attention to bring up to a level in which they can confidently work in a complex geologic environment (Ishikawa & Kastens, 2005; Riggs et al., 2009). The lack of field learning opportunities for students with disabilities (see Section 4.3.1) only added to the frustration for the SWD cohort that novices often feel in the field. With few field opportunities in their academic backgrounds, field work itself was a new experience for some. As was illustrated at the first location in the Recess mapping project (the Fish Hatchery), when this deficiency in prior academic experience is not taken into consideration in the design and execution of learning exercises, the knowledge gap can become a source of frustration and directly impact academic engagement. When combined with physical barriers to participation, that frustration evolved into feelings of exclusion (Section 4.3.2, Academic>Content).

One of the challenges of remote collaboration in terms of learning is the cognitive task of making connections between information that is situated in different contexts (Adams et al.,
Some teams attempted to better understand the geologic context and potential relationships between field sites by searching online for research articles in their downtime or by relying heavily on teammates to provide the knowledge required to understand the geologic problem at hand. In the case of Team C, social strain developed when teammates could not adequately fill the knowledge gap (4.3.2, Social Teams & Partners).

An examination of video footage indicates that students with less relevant academic background took on mostly passive roles in the data collection process during synchronous collaborative field activities, allowing their partners in the field to make decisions about what to do, what to document, and what data to send back from the field (Section 4.1.2). The one remote participant with significantly more field experience (B1) took a much more active role in the direction of field activities than the other remote participants, and thus had significantly higher levels of engagement. Collins et al. (2010) notes in an early trial of remote collaboration in an advanced level geology field course that remote participants made numerous specific requests as to imagery they wished to see from the field; which was in contrast to trials in other courses where less experienced students requested very little in addition to what remote partners chose to send. It stands to reason that students who understand more about how to conduct field work in person would be able to engage more in field work conducted virtually. The small number of participants in this study leaves this potential linkage unsubstantiated, but if there is a link between the effectiveness of this approach and the level of prior experience a student may have, this may have implications as to how and when this technique can be used effectively.

5.2.2 Theme 2: Academic Inclusion.

The wide range of academic backgrounds provided an opportunity to examine the theme of academic inclusion – creating an environment where people at a range of skill levels can
productively engage in learning activities. Inclusion from peers and leadership are both important in creating an academic environment where students feel empowered to engage in learning activities. The structure of learning activities, expert guidance, technology and social climate all influence academic inclusion.

**Format of learning activities.**

The structure of learning activities can promote or decrease feelings of academic inclusion and student engagement. For example, participants at all skill levels felt the emphasis placed on description over interpretation during the activities of the second-year field trip allowed students at all skill levels to contribute to documentation and data collection activities (Section 4.3.2, Academic>Field Work>Format). However, Survey and Interview data indicated that some students felt the format of some exercises constrained members of each cohort to specific academic tasks, specifically SWoDs as data gatherers and SWDs as data interpreters (Section 4.2.2, Qualitative Survey, and Section 4.3.2, Social>Teams & Partners). This sentiment hints at potential issues with either team dynamics or how faculty instructions were interpreted, or perhaps both. Nothing in the format explicitly excluded members of the SWoD cohort from participating in the interpretation or synthesis of data, and in a many of exercises, members of the SWD cohort were expected to participate in data collection. Yet perhaps the general format of the field activities, where SWoDs were referred to as the “field” or “away” team, and the SWDs as the “base” team contributed to this division of tasks by cohort.

The structure of learning exercises did have an influence on the degree to which students collaborated during an exercise. At Recess, two members of each team worked at separate locations. Qualitative data indicates several potential reasons for the low levels of collaboration between team pairs during the Recess mapping project. But more importantly to the discussion
of format influencing communication, the preceding exercise at Kilkee where the format was a ‘gather now, report later’ style of data collection (Section 3.4.2, field site #1) may have encouraged students to continue that approach at Recess. In this case, the format of the preceding exercise may have influenced the level of collaboration at the following exercise.

While student’s opinions of the format of the Recess exercise were not especially positive, a significant boost in feelings of academic inclusion, accomplishment and engagement came from the shared task of constructing the collaborative structural map of the Recess area. Students were excited to see how the work they were doing at each outcrop contributed to a larger product. It has been noted by others that field work that contributes to larger collaborative projects have a significant impact on enhancing engagement in the immediate activity and also boosts motivation in future coursework (Gonzales & Semken, 2009; Marshall et al., 2009). This map validated the work that each group carried out in the field and illustrated how the data from each outcrop was important to the final product of the exercise.

The majority of students felt that academically, the first-year field trip was more inclusive to a wide range of academic experience levels. In the second year, students felt overwhelmed in the geologically complex terrain of western Ireland. This feeling was magnified in the SWD cohort, who felt that field activities designed to include students with disabilities should account for the lack of opportunities in the academic backgrounds that were the result of systematic discrimination and exclusionary practices (Section 4.3.1>Academic Background>Previous Field Work).

**Guidance and Leadership.**

Students reported an increase in engagement and learning when experts were available at the outcrop with students, and field observations support these statements. The presence of
faculty who did not possess expertise on topics relevant to the field sites were not sufficient to improve academic engagement and motivation (Section 4.3.2, Academic>Content>Guidance). It is not unusual for undergraduates to require guidance and assistance from knowledgeable practitioners, especially when working in a geologically unfamiliar environment (e.g. deep sea terrain, Pallant, McIntyre, & Stephens, 2016). The highly complex metamorphic geology of western Ireland was not familiar geologic environment for most participants, and the desire for expert guidance during the second-year field trip may be related to the large novelty space produced by the location. It may also simply be related to the overall feelings of academic insecurity from a number of the participants, as more experienced learners typically prefer to work more autonomously from instructors (Stokes and Boyle, 2009).

**Communication and Information.**

Information is necessary to allow students to plan appropriately for academic activities and is a key factor in facilitating learning (Orion & Hofstein, 1994). Each participant needs a clear understanding of what they are expected to do and how they are expected to utilize the tools given to them; especially important when incorporating an unconventional approach such as remote collaboration. A lack of communication and conflicting information from faculty caused confusion in the field and negatively impacted the use of communication technologies early in the week of the second field trip (4.3.2, Tools & Tech>Communication). When the use of communication technology was clearly articulated as a priority late in the week, engagement and feelings of inclusion dramatically improved.

A prime example of how a lack of information directly affected academic activity and collaboration in the field occurred during the Recess project when many of the students were not aware they should be looking for potential relationships between the outcrops that each group
was documenting. As a result, team mates did not feel the need for frequent contact with team mates during the day (4.3.2, Tools & Tech>Communication). For the advanced students who typically conduct research at the Recess field site, instructors would not have to explain that the outcrops were likely related, but for a group of students with little experience in structural mapping, this information was important to understanding how best to document the field site, as well as understanding the importance of collaboration throughout the day.

In the second year of the project, students felt as if they lacked the necessary information to personally prepare for field activities (4.3.2, Academic>Guidance & Information). This made gauging how to spend their time in the field was difficult. For students who may have special considerations when planning for outdoor activities, this information is even more vital for successful participation as the lack of information regarding terrain, activities and expectations has been shown to be a significant deterrent to participation in outdoor activities in natural settings (B. Lee et al., 2012; Yau et al., 2004) and to field work in particular (Hall & Healey, 2005).

The qualitative results of this study also indicate that the degree to which a location was physically accessible was not as important to affective outcomes for participants with disabilities as the expectation of accessibility. When the expectations of accessibility matched the reality and appropriate tools for overcoming potential barriers to participation were available, students had positive impressions of the location in terms of inclusion, even if the location was not fully accessible. When their expectations did not align with the reality in the field, and/or the appropriate tools were not in place to equip the students to participate in a meaningful way, students developed highly negative impressions of the exercise. This is yet another reason communication is vital for successful participation of students with disabilities in the field.
Accurate information regarding accessibility combined with the training and tools to implement alternative means of access could help students adapt more easily to unexpected field conditions.

**5.2.3 Theme 3: Social Inclusion.**

Streule and Craig (2016) liken geoscience field work to hospital residencies for medical students; a complex real-world learning environment where academic and social interactions are closely intertwined. The level of social engagement in field learning can have a significant influence on learning outcomes (Elkins & Elkins, 2007; Stokes & Boyle, 2009).

Qualitative data shows that the participants believed that creating a socially inclusive atmosphere improved academic engagement because individuals felt comfortable sharing thoughts and ideas. This aligns with the literature that supports a clear link between social climate and academic outcomes (Lave, 1996; Streule & Craig, 2016; Wenger et al., 2002). The results of this study show that the factors that may influence social engagement include many of the same factors that influence academic engagement including the format of learning activities, guidance/mentoring, communication, collaboration.

**Team Structures.**

Each team developed a unique social dynamic over the course of the second field trip. Team A exhibited a strong group identity, and it was remarkable how cohesive their narrative remained, even when members were separated into different interview groups. Data from members of Team A merged together with little to no contradiction, and described a group focused on acquiring knowledge and achieving their goals for the project (see Section 4.3.2, Student Goals). Team B exhibited strong group identity amongst most of its team members, though one member struggled with their identity within the team’s social structure throughout the week. Team C diverged from the other two teams in almost every measure of social
cohesion. The social fabric of Team C was compromised early in the week when one member quit the project entirely. Qualitative data shows no evidence of the development of unified goals or commonality of purpose for members of this Team C, and clear examples of social exclusion (the SWD team mates intentionally excluding the remaining SWoD team member) were observed during downtime. This lack of social cohesion appeared to affect their ability to work effectively in the field, as one student in Team C admitted that their finished assignments were “sub-standard, at best (C3, Focus Group, year 2)” compared to what the other teams had done. Participants’ feelings about the fixed teams may be linked to each group’s social cohesion. Team A had the strongest group cohesion and team identity based on observations in the field and interview data, and all members of this team reflected positively on the fixed-team structure. Team B also displayed a strong group identity amongst most of its members and worked well together. The one member who struggled with social identity within Team B was the only one to voice a preference for the rotating partner format from Arizona. All of Team C struggled with forming a cohesive team identity, and all members of this group expressed a preference for rotating team members.

*Format of learning activities.*

As other researchers have pointed out, communication technology can provide a form of access to field work, but it is only through active participation that inclusion can be achieved (Collins, Davies, & Gaved, 2016). The format of learning activities plays a significant role in providing opportunities for social and academic engagement. The synchronous format used at Renvyle Point enabled partners from both cohorts to work together on a single task or objective which created the strongest capacity for collaboration and social inclusion in the team. The preference for a unified task was an important reason for the positive feelings regarding the
exercise at Renvyle Point. Although the SWD cohort was physically isolated from the field site, this exercise was held in high regard by all participants in terms of social inclusion, team building, and collaboration. Participants were vocal about their dislike for the division of working groups into able/disabled groups during the Recess mapping project, which was viewed as detrimental in terms of both academic and social inclusion. By splitting the teams in half by physical ability for a multi-day project, students began to feel segregated by ability (Section 4.3.2, Academic>Field Work>Format). Opportunities for social bonding are among the aspects students most value about field work (Scott et al., 2012), and by limiting the interaction the cohorts had in the field, these opportunities for social interaction were greatly reduced.

In terms of individual inclusion, students were strongly opposed to decisions regarding access being pre-determined for all the members of the SWD cohort during the Recess exercise and were emphatic that each participant should be empowered to make their own decisions regarding which parts of a field site s/he could safely access (Section 4.3.2). This echoes the theme of the importance of personal empowerment in decision-making noted by Atchison (2011) in a study regarding cave access for students with disabilities.

Formats that provide the opportunity for physical challenges have been cited in the literature as an important aspect of social bonding in the geosciences (Mogk & Goodwin, 2012). The sense of accomplishment with overcoming shared hardships, both academically and physically, is in part what makes field work such a memorable experience (Stumpf, Douglass, & Dorn, 2008). Physical challenges may look very different for students with diverse physical abilities when compared to able-normative students, but the results of this study indicate that these experiences are no less meaningful in terms of generating confidence, a sense of accomplishment, and personal ownership of the field learning activities.
While physical challenges are important as affective experiences, care must be taken that these physical challenges do not put the student in danger of causing harm to themselves that could curtail their ability to participate. In this study, one participant (B2), reported a boost in confidence and sense of accomplishment from completing the Trail of Time, but missed opportunities to participate the following day due to the physical repercussions of pushing beyond what for them were safe levels of exertion (Section 4.3.2, Field Work>Physical Challenges & Accomplishments). These results indicate the need to consider field locations where a range physical participation options and opportunities can be explored, but more importantly, a social setting where students are not socially isolated if they choose not to participate in a physical challenge.

**Guidance and Leadership.**

The role of faculty in promoting inclusion and engagement goes beyond their role as designers and facilitators of learning exercises. As has been noted in other studies (e.g. Stokes & Boyle, 2009), the results of this study indicate that participants assigned a great deal of worth to the time invested in them by experts in the field. When expert practitioners invested their time and expertise in a novice student, it enforced the idea that the student was valued as a member of the field team and capable of making meaningful contributions (Section 4.3.2, Social>Whole Group). Time spent with experts was especially important to members of the SWD cohort who explained that having an expert present to provide guidance was not only helpful for academic improvement, but also helped overcome feelings of exclusion that a lack of full access sometimes prompted (Section 4.3.2, Social>Faculty). Other studies have highlighted the importance of mentorship in enhancing feelings of social belonging in communities of learning (Callahan et al., 2015) and social, and have shown that for students with disabilities in STEM
fields, rapport with instructors was the single biggest influence on persistence through difficult assignments, confidence-building, and academic motivation (Jenson et al., 2011).

Peer leadership also played a role in developing a climate of social inclusion. Participants in the field watched each other for social cues and ideas on how best to improve the social experience for their remote teammates. One student remarked that watching a student from another group carefully film details at a field site prompted a conscious effort to consider the perspective of remote team mates and modify their own approach to filming (Section 4.3.2, Social>Teams & Partners>Inclusion). This illustrates how cultural attitudes can be passed from person to person within a social group, and how a culture of inclusion can spread when good practices are modeled by peers.

Participants stressed the importance of communication - between faculty and students, and between teammates - as one of the most important influences on social inclusion in and out of the field, supporting other findings that indicate social interactions in the field provide significant long-term benefits to learners in terms of social identity and future success within the geosciences (Gold et al., 2003; Mogk & Goodwin, 2012; Streule & Craig, 2016).

Social Identity.

Social interactions in the field can provide significant long-term benefits to learners in terms of social identity and future success within the geosciences (Gold et al., 2003; Mogk & Goodwin, 2012; Streule & Craig, 2016). The unique student population of the GEOPATH project provided the opportunity to examine social engagement in a field setting where students of all physical abilities are active participants in field activities.

Over the course of the project, the students realized that given a variety of circumstances, such as illness or injury in the SWoD cohort, or the fluctuating nature of some of the SWD’s
physical conditions, the boundary between able and disabled was difficult to determine on a day to day level. As a result, all the participants felt strongly that all students should be able to make their own decisions as to where within the field site they would able to work, regardless of whether they identified as disabled or not. As one SWoD explained at the end of the second-year field trip, one of the lessons learned was that “At some point, it doesn’t matter how physically able you are… you reach a certain limit where it doesn’t matter how ‘able’ you are; there’s gonna be a limit to where you can go (B3, Focus Group, year 2)”. This conceptualization of disability is closely aligned with the social model of which frames disability as a social construct (Oliver, 1996).

One of the interesting impacts of promoting inclusion for the participants with disabilities was how the ideas of inclusion and support were applied to all students, regardless of disability identity. Students in the SWoD cohort began to be more conscious of other students’ needs, even within their own cohort. One participant in the SWoD cohort shared how the inclusive atmosphere ease concerns about attempting field work as a diabetic (4.3.2, Social>Individual Social Identity). Although this student did not identify as disabled, there was significant concern about going out in the field. This student explained that the atmosphere of support and inclusion eased the sense of worry and encouraged participation in future field work opportunities.

Students expressed how the atmosphere of inclusion during the GEOPATH project was different than what they experienced at their home universities and allowed them to be more comfortable expressing ideas and engaging more actively in learning activities (4.3.1., Social Background). Social Learning Frameworks account for this important aspect of learning. As Wegerif (1998) explains, “without a feeling of community, people are on their own, likely to be anxious, defensive, and unwilling to take the risks involved in learning (p.48)”.

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5.2.4 Theme 4: Collaboration.

Collaborative learning in the field can enhance academic engagement, increase understanding and improve confidence amongst team mates (De Paor & Whitmeyer, 2009; I. Fuller, 2006). Video footage (Section 4.1.2) supports interview data showing that that collaboration between students at different academic levels was viewed a beneficial arrangement for all parties. Novice students gained knowledge from more advanced students, and more advanced students had the opportunity to put their knowledge to use and gain confidence in their abilities by guiding less-experienced peers. This aligns with the concepts behind the Communities of Practice framework where groups of people deepen their knowledge through interaction with one another (Wenger et al., 2002). As with other collaborative projects (e.g. Adams et al., 2011; Pallant et al., 2016), students felt they benefited academically from remote collaboration. While this evaluation does not attempt any sort measurement of learning outcomes, the positive response from participants regarding the building of knowledge as a result of remote collaborative activities contributes to other informal reports of positive academic outcomes in remote collaborative field work.

Survey responses revealed an interesting result regarding team structure and its influence on feelings of inclusion. When team members were working through remote collaboration from different locations, several Survey responses stated that neither party (direct field participants or remote participants) should be physically alone (Section 4.2.2). This preference for physically-present partners illustrates that while remote collaboration can provide a means of access, it may not be enough to counter the feeling of social isolation if a participant is working alone.
**Synchronous vs. Asynchronous Collaboration.**

In the first year, students had mixed opinions on their preferences for synchronous or asynchronous collaboration with some students clearly expressing a preference for the semi-autonomy provided by the asynchronous approach. In the second year, students overwhelmingly preferred the synchronous approach over the asynchronous approach. However, in the first year of the project synchronous collaboration with technology was only used for a few minutes and synchronous work was conducted in-person rather than remotely.

In comparing the outcomes of engagement in synchronous vs. asynchronous approach during the second-year field trip, it must be noted that students did not realize until the conclusion of the exercise that the field locations sites at Recess were closely related. Many students had incorrectly assumed the work at each outcrop was not directly related to the work being done at other outcrops, and therefore team members did not feel the need for frequent communication between working pairs while in the field. Had the students realized how the outcrops were potentially related to each other, it may have significantly changed the degree of collaboration and the levels of academic and social engagement for the asynchronous exercise.

Asynchronous collaboration generated academic engagement by the consideration of what information would be beneficial for a team mate who was not physically present to understand the field site. In determining what to document for team mates, students reported that they “gained confidence in geology knowledge and clarified [their own] ideas (Anonymous, Survey, year 2)”. Asynchronous collaboration was considered far less effective than synchronous collaboration in terms of team-building and social inclusion. Qualitative data indicate that participants felt the infrequent interaction with team mates working at other locations during the asynchronous exercise at Recess was detrimental to social engagement and feelings of inclusion.
This agrees with other studies that indicate asynchronous collaborations may produce similar academic outcomes, but are not as effective as synchronous collaboration in terms of social engagement (Hiltz, Fjermestad, Ocker, & Turoff, 2006; Rockinson-Szapkiw, 2009).

The results of the video analysis and qualitative survey items from the second year indicate synchronous collaboration was regarded as highly beneficial to social inclusion. Sharing photos and videos in real time “allow[ed] everyone to feel included because everyone had the opportunity to point something out and discuss it (Anonymous, Survey, year 2)”.

**Student Goals.**

In a collaborative learning environment where no grades were given, students employed another way to motivate participation and measure success by conceptualizing goals for their teams and for the project overall. By identifying ways to make what they believed were meaningful contributions to the ideals of GEOPATH project, a framework was created in which to gauge success for themselves, their teams and for the project. In the second year of the project where students were assigned the same team members for the duration of the week, the consistency of these goal statements, even when individual team members were separated into different focus groups, indicates that team members likely discussed their ideas together and developed these goals as a team. These student-created goals influenced how members of each team spent their time in the field and what aspects of the field experience were prioritized, directly influencing engagement.

The importance of these goals to team members can be seen in the topics that members of each team chose to talk about in interviews. Team A, who felt the primary goal of the project should be to ultimately produce an approach to field work that could be implemented in other field courses, focused on developing and documenting a collaborative approach that focused on
social inclusion and strong academic results. In interviews, students in Team A discussed in detail things that worked and what could be improved in future iterations. When given specific academic assignments, Members of Team A worked hard to produce high quality academic products, perhaps to provide further evidence of the success of their approach. Team B was also motivated by the goal of developing an approach that could be exported to other settings but were also motivated to examine the potential of the technology itself. In the field, members of Team B invested time in experimenting with novel uses of the technology in the field for data collection and documentation. In interviews, members of Team B shared specific technical details on the function and potential future use of technology in inclusive field learning environments.

**Defining Roles.**

In blended learning environments, collaborative activity can be guided by rules and/or internal guidance by the software used to communication, or the approach to collaboration can be left up to team members to decide how best to delegate tasks and communicate with team mates in other locations (Hiltz et al., 2006). Collaborative activity during the GEOPATH project falls into the unstructured approach, as communication and collaboration were not constrained by guidelines or rules regarding the types and frequency of interaction between team members, or the roles each team member should take in facilitating communication. Specific roles were not formally assigned for the team members in this study, but the students nonetheless took cues from faculty instructions, the format of the learning activities, and from inter-team dynamics to devise roles for themselves in the collaborative process (Section 4.3.2, Social>Teams & Partners>Inclusion).
In the RAFT project, the assigning of roles was linked to increased engagement for remote participants during remote collaborative learning activities (Bergin et al., 2007; Hine et al., 2004). For some of the participants in this project, the self-directed assumption of roles had a negative impact on the social dynamic when the roles they created for themselves resulted in unrealistic expectations as to what they and other participants should contribute to their teams. This may have been part of the social strain observed in Team C, where teammates on each side of the collaboration seemed to expect the other teammates to do significantly more than what was accomplished. When the roles assumed by team members were based on more realistic expectations, the application of their collaborative skills and abilities produced engagement and a cohesive team structure. Teams A is an excellent example of how students defined roles based on prior experience, personal interest, and inclusion and were able to successfully collaborate in a way that made all team members feel engaged and valued.

5.2.5 Theme 5: Technology.

The technology incorporated into the GEOPATH project played a large role in improving academic engagement for all participants (Section 4.3.2, Tools & Technology>Data Collection). The focus of this evaluation is not on the use of technology specifically, however there are several technology-related influences on engagement that are worthwhile to discuss. Students appreciated the adaptive capabilities of the tablets, which allowed for a range of options that improved accessibility such as voice-to-text, and the capability to finger-sketch rather than manipulating a stylus. The ability to make sketches on photos helped convey and clarify ideas and the ability to and share photos and videos with team mates promoted academic inclusion. By reviewing videos with team mates, the extra opportunity to engage with the field site enabled students to notice details about the field site that were not noticed when in the field.
The communication technology employed for synchronous remote collaboration did present a few challenges that may have influenced engagement. The increase in time spent on technical issues in the remote group compared to the group with direct access to the field site is likely due to the increased reliance on technology that remote participation requires. Students participating remotely were using a variety of apps on their digital devices to communicate with teammates, take notes, and document geologic information. Students directly participating were using only the data collection and note-taking apps. Additionally, the GEOPATH project was designed to test-run apps that had not been field tested yet, and some of the communication apps were more prone to technical issues, which also contributed to the increase in time spent on troubleshooting.

Previous projects have utilized video cameras as a means of sharing the field experience with remote participants (Stokes et al., 2012), but the distribution of wearable video cameras at an individual student level is relatively new. The ability to record a first-person view of their activities in the field with wearable cameras was highly valued by all participants for data collection (Section 4.3.2, Tools & Tech>Data Collection), as well as a means to include their remote teammates in the exploration of a field site (Section 4.3.2, Teams & Partners>Inclusion).

The high value that students placed on the technology also created an unexpected influence on academic motivation and attitude, as students interpreted the distribution of technology as an indicator of the importance of the work being done at a given location (Section 4.3.2, Tools & Tech>Distribution of Technology). When the SWoD cohort were initially given priority in the use of the wearable cameras, it inadvertently sent the message that the locations being documented by the able students were more interesting or more important than the locations being documented by the students with disabilities. When the SWDs were not given
wearable cameras, the group took that to mean that the area they were documenting was of low value to the overall mapping project. The lesson here may be that when utilizing technology as a means of increasing inclusion, some thought must be given to the distribution of technological tools and how students might interpret that distribution as statement on the importance of the work being done.

One of the unexpected challenges for the students participating through remote collaboration was the volume of information coming in from the field. Videos and photos on their tablets from multiple apps, verbal descriptions and discussions over the radio, and physical rock samples delivered by faculty all required attention. Studies have shown that in highly immersive virtual learning environments, engagement can suffer when too many things vie for attention at once (Lin et al., 2011; Nelson & Erlandson, 2008), and video analysis shows that students working remotely did have difficulty managing the inflow of streaming video, photo and verbal information while also attempting to make their own notes and documentation. This challenge of information management has been touched on in other trials of remote collaboration. Coughlan et al. (2011) observed students on both ends of the collaboration “information-filtering (p.94)” in deciding what to send to teammates during the remote collaboration in the OTIH project (see Section 2.8 in the Literature Review). During the synchronous exercise at Renvyle Point in this study, students in the field took a less measured approach to sharing information and as a result, remote team mates had to determine how to manage the influx of un-filtered photos, videos, rock samples, and radio conversations. Two of the remote teams adapted by utilizing the video cameras mounted in the vehicles in which they were working to document conversations and their own audio notes during the exercise. This
informal adaptation seemed to work well, but in future iterations of remote collaboration, some thought should be given to techniques that might streamline or improve this process.

One of the benefits to the send-it-all approach to data sharing in terms of engagement was that field students were not filtering information for the remote students. One of the educational challenges in participation through remote collaboration discussed in earlier trials is that the remote participants are entirely dependent on their field partners for selecting what to document and what data to send (Coughlan et al., 2011; Davies et al., 2010). While the flood of information was sometimes overwhelming, the un-edited perspective of the field site enabled remote students the opportunity to process the site in much the same way as they would with direct access, and actively collaborate with field partners in deciding what aspects to focus on for closer study and what data to collect. This was an especially useful approach for Team B, where the two students in the field were novices and one of the remote team mates was far more experienced.

5.3 Novelty Space

The outcomes of this study are also clearly aligned to the concept of Novelty Space which contends that the potential for meaningful learning experiences in the field are influenced by the degree to which students understand and are comfortable with the academic, physical, psychological and social aspects of the learning activity (Mogk & Goodwin, 2012; Orion & Hofstein, 1994; Stokes & Boyle, 2009). Novelty space is especially relevant to this study of engagement because some researchers have pointed out that the extra concerns regarding field conditions and physical requirements create a novelty space for students with disabilities that is likely much larger than able-normative participants (Hall & Healey, 2005). Examining an exercise that produced a large novelty space during this project, and one that produced a much smaller novelty space, highlight the potential influence of Novelty of field learning experiences.
5.3.1 Large Novelty Space: The Fish Hatchery.

An example of how a large degree of novelty space for students impacted their learning outcomes can be seen in the experiences of the SWD cohort on first day of the Recess mapping project at the Fish Hatchery (see Section 3.3.2, field site #2, for description). This site was the first location in a new landscape on an international field trip in a geologically complex setting. The location had been described as an ‘accessible’ field site, yet students were frustrated to find that for many of them, the outcrop could not be accessed directly due to environmental barriers (Academic>Field Work>Terrain & Accessibility). The SWDs, with little prior field experience, were frustrated by the fact that the faculty experts on the local geology had gone with the SWoDs to their field site (4.3.2, Academic > Content > Guidance), and that many of the technological tools had not yet been introduced or had been sent with the SWoD group (4.3.2, Tools & Tech > Distribution of Tech). With no experience to draw from, and little guidance, many were at a loss at to how to collect the data they needed. The SWD cohort interpreted the lack of on-site expertise combined with the assignment of fewer technological tools as compared to the SWoD cohort as an indication that the work at this location was of low importance to the outcomes of the larger mapping project. Furthermore, the physical separation of teammates from each cohort, with little communication between the two groups, created a socially isolating atmosphere in the field. The result was a learning experience that negatively influenced the SWD’s perceptions of the social climate for the remainder of the week, and an academic product that was far below the expected quality for the participants. Upon reviewing the data collected by teammates at the Fish Hatchery, a student in the SWoD cohort described their academic outcomes as “a hollow version of a field experience (Section 4.2.3, p. 103)".
5.3.2 Small Novelty Space: Renvyle Point.

When the components of Novelty Space are effectively addressed, even unconventional learning activities can be highly effective. The glacial mapping exercise at Renvyle Point, using synchronous remote collaboration, generated the most positive feedback in terms of both academic and social inclusion of all the exercises during the second field trip. This exercise was the last one of the week, and the students had acclimated both to their teams and to the international setting. Academic engagement had been improved over the course of the Recess project by improving access to faculty expertise for members of the SWD cohort. As an added boost to feelings of inclusion, student viewed the results of the collaborative geologic map from the previous exercise the night before the Renvyle Point exercise.

Concerns about the weather conditions – cold, windy, looming rain clouds – could have expanded the Novelty Space for the SWoDs working in the field. However, the faculty made a point of acknowledging the weather, explaining exactly how far they would be going, what the terrain was like, and what time they would be coming back to vehicles. For the SWD cohort, concerns about weather and terrain were taken out of the Novelty Space entirely by working from inside vehicles.

In terms of academic Novelty Space, students felt that for the first time all week, faculty and students were on the same page regarding plans for the day, desired outcomes, and the approach to conducting field work. This unified sense of purpose was highlighted in the post-trip interviews as a key source of motivation for this exercise, and the ability to work synchronously together with their teammates for the first time all week strongly enhanced feelings of inclusion and social engagement. The result was an academically and socially positive learning experience that generated feelings of accomplishment and inclusion for all participants.
5.4 Limitations of current study

The STROBE observation protocol has not been verified for use in geoscience field learning settings. In terms of comparing engagement for direct and remote participants, the fact that each group was analyzed during a different exercise presents a threat to the validity of comparisons between groups. This limitation is mitigated by the focus on engagement and not on specific learning outcomes, but it still diminishes the validity of the comparison. Strong inter-observer agreement indicates this approach may be a reliable measure of engagement, but modifications to a previously verified approach threatens the validity of results. The social presence survey was administered with two unverified open-response items. The wide-ranging topics addressed in the responses suggest some refinement in these prompts may be required to generate responses that related directly to the social environment of the remote/virtual interface and improve validity of these items.

5.4.1 Limitations of Research Context.

The GEOPATH project provided an excellent environment to study engagement through remote collaboration and the field work experience for students with a range of physical abilities, however some limitations on this research are a product of conducting this research in the context of a larger project. Some limitations result from lack of control over data collection methods. Interview data was collected in significantly different formats in year 1 and 2. Some of the differences in tone, and what students chose to share in interview may have been influenced by these differences in format. Additionally, many researchers are working with data from this project and as a result, some data sources that would be relevant to this evaluation were not included. It must be acknowledged that the data examined here is only a sub-set of potentially relevant data.
5.4.2 Bias of the researcher.

It is important that the researcher in a study that relies on the interpretation of qualitative data remain as neutral as possible from the subject of study. However, the researcher served as a graduate research assistant on the project and was involved in planning, logistics, and student experiences throughout the GEOPATH project. In addition, as a person who identifies as a geoscientist with a physical disability, the conscious effort to remain a neutral party was not always successful. In instances where participants were struggling in the field due to physical or environmental challenges, it was often the case that the researcher was struggling as well, which may have influenced the observations being made. On the other hand, researching this topic as a person with a disability may allow for insights that would not emerge from an able-normative perspective. Some researchers assert that scholarship regarding the disability community suffers from a near-total lack of voices informed by the perspective of disability, and that research conducted from within the community is greatly needed (Humphrey, 2000; Kitchin, 2000). Care was taken in the analysis and interpretation of qualitative data to minimize potential bias as outlined in Section 3.7.3, and through the use of multiple data sources to support findings.

5.5 Implications and Future Research

Geoscience Education.

The results presented in this paper have implications for future research regarding field learning for all students. This research builds on other studies of engagement in field learning environments and offers a potentially valuable way to examine engagement through the application of a quantitative video analysis protocol. Over time, the video analysis protocol introduced here may be refined into a robust and well-validated tool that would allow comparisons across a variety of field course formats and student populations.
The lack of field opportunities for students with disabilities can put them at an academic disadvantage compared to their able-normative peers. This differences in academic background must be accounted for when designing inclusive field experiences, and research on building supportive academic communities in the context of the geosciences would be valuable as well.

The results of this study demonstrate that the social dynamic present outside of the collaborative learning activities can have a significant influence on social engagement during the collaborative activity, and vice versa. Social inclusion may be even more important in field learning environments where students are likely to be operating well outside of their comfort zones in terms of academic, geographic, or physical norms. Yet social inclusion cannot be taken for granted or expected to simply happen, it must be actively cultivated in and out of the field.

Physical barriers to participation may not be immediately apparent. Walking long distances, even when paved, can be a significant barrier to students who are able to walk but have limits in terms of endurance. Conversely, a powerchair user would not consider distance on a paved surface a barrier, but a single curb or step might prevent their participation. And while the focus of access is often centered around physical barriers in the terrain, field work can also present less-obvious challenges to students, including difficulties in manipulating equipment or digital devices. The implication here is that students need to feel socially comfortable sharing accessibility needs with faculty, and faculty need to be flexible in terms of how a student can most productively participate in the learning activities in the field. Further, successful approaches to inclusion need to be shared with the broader geoscience community.

While the study of accessible field learning is vital to developing and improving approaches to inclusive geoscience field work, the implementation of these approaches in for-credit field courses is an even greater need. In the US, there are currently no fully accessible field
stations, and for-credit field opportunities for students with disabilities remain extremely limited. Reactionary or on-the-fly accommodations are often difficult to execute and academically inferior. It is imperative that we develop ways to include students of all physical abilities in field learning alongside their peers. The development of inclusive field courses could be aided by establishing vetted locations in popular field learning destinations that have the capacity to support inclusive field experiences. Using the same location over many studies could eliminate one of the largest variables when trying to compare the results from different studies and would allow many researchers to contribute to greater understanding of inclusive learning experiences. If one academic institution were to develop an inclusive field camp based in the same area each year, every summer would offer a new opportunity to research and refine inclusive techniques.

**Virtual and Remote Field Work.**

The integration of technology in field learning environments has been described in the literature, but rarely examined for the potential impacts on engagement or learning outcomes in any detail. As technology is likely to become more prevalent in the field, research regarding all aspects of academic and affective outcomes of technology-enabled field work are greatly needed.

In terms of virtual field work, this study indicates that productive levels of engagement can be achieved through remote field learning environments. However, the findings regarding the impact of social inclusion and the importance of physical engagement on academic engagement bring up questions regarding how to translate these ideas into fully virtual learning environments.

In terms of the approach examined in this study, remote collaboration, there are some potential issues that should be considered in future implementations. The assumption of roles by physical ability that was the working premise much of the GEOPATH project brings with it the
question of how to adapt this approach to situations where students do not have the academic experience to enable them to perform well in those roles. The scenario of a novice geoscience student put in the role of team data-interpreter based on limited physical ability could result in significant frustration on the part of the student as well as the student’s team mates when the student is underprepared academically to fulfill that role. This is where expert guidance would be absolutely necessary to during field learning exercises to bring the student up to a level of comfort with academic task at hand.

**Disability Studies in the Geosciences.**

The research presented in this study contributes to the relatively sparse research regarding students who fall outside of the traditionally accepted able-normative model of a geoscience practitioner. While descriptive or anecdotal literature is available to a small extent, the topic is not well represented in terms of research. There are many useful avenues of inquiry that would help define the landscape of the problem including examinations of student experience and barriers to participation. Examining the social/cultural aspect of the geosciences may be a good opportunity for interdisciplinary studies with researchers in other fields such as sociology.

Individuals with disabilities who have had success in the geosciences may actively work to hide or downplay their disability for fear of academic/career consequences (e.g. Serrato, 2017); a phenomenon which has been documented in other STEM fields as well (Taub et al., 2004). As a result, personal strategies as to how to adapt, innovate, and advocate for access are difficult to find. These personal strategies could be incredibly useful to new students in helping them sort out how to succeed in the field, and the responsibility of sharing this information is two-fold. First, those of us who have successfully overcome challenges in the geosciences need to share what we have learned to empower others to do the same. Second, the geoscience
community has a responsibility to address the parts of our culture that make members of the community feel there is too much risk to their academic, social or career prospects by being open and honest about this topic.

5.6 Summary and Concluding Remarks

Technological advances have given educators more options for providing students with opportunities to participate in geoscience field learning environments including a variety of virtual and remote interfaces. An evaluation of engagement provides a solid first step in gauging the potential academic and social impacts of remote collaboration and similar technology-based approaches to field learning.

The results of this Video Analysis indicate that cumulatively, collaboration through technology can enable engagement levels similar to those produced in direct field experiences (Section 4.1.1). At an individual scale, engagement in both direct and remote field work can vary a great deal, even amongst students working together (Section 4.1.2 & 4.1.3). The results of the Social Presence Survey indicate that participants felt that remote collaboration had the capacity to support meaningful social interactions and social engagement (Section 4.2.1). However, the academic backgrounds of students, the structure of learning exercises, the format of the field work, and the delegation of resources (knowledge and tools) can all have an impact on engagement (Section 4.3.2).

Remote collaboration is successful in fostering engagement when learning activities are conducive to communication, and students are comfortable with the use of the necessary tools, technology and techniques. The conceptualization and implementation of goals may serve as key sources of motivation in collaborative settings and significantly influence academic outcomes. The influence of social inclusion on academic engagement cannot be underestimated, and the
results of this study illustrate how inclusion can have positive impact on any learner working in a collaborative format.

Remote collaboration supported by communication technology can be a valuable means of access in inclusive field learning environments. Yet technology cannot be viewed as a stand-alone solution to inclusion in field learning environments. As with any educational tool or approach, it must be incorporated into a larger educational strategy to be effective means academic and social inclusion. Issues such the lack of field learning opportunities for underrepresented populations and the resulting academic deficiencies need to be taken into consideration when planning learning exercises, and the format of learning exercises must be critically examined for barriers to social interaction that may result in feelings of isolation or exclusion.

The need for expanded access to inclusive field learning opportunities impacts a far larger group than those who identify as disabled. Injury, pregnancy, age, physical fitness and a host of other reasons can limit one’s ability to physically participate in direct field activities. Yet as a community, geoscientists place a high value on physical capabilities in the outdated notion that physical ability is a requisite to success as a geoscientist. This artificial cultural barrier continues to be the most challenging barrier to overcome. Modern technologies and inclusive approaches to conducting the business of geology provide valuable tools to bring a more diverse population into the geosciences, but without changing the culture, efforts at recruiting and retaining a diverse population of geoscience practitioners will not improve. Both aspects must be addressed in tandem; providing the missing academic support required for successful completion of a degree program and providing the cultural support that will enable individuals of all physical abilities to be integral members of the geoscience community.
References


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Appendix A: AGI Disability Inclusion Statement

Consensus Statement Regarding Access and Inclusion of Individuals
Living with Disabilities in the Geosciences
Washington, District of Columbia

June 2015

The geosciences are central to understanding the interaction between the Earth system and humankind and are vital to global economic and social development. As a community, it is important that we are inclusive, welcoming, and open to all members of society. The geosciences face challenges in securing the workforce necessary to meet the needs of the coming decades. To increase talent and diversity in the geoscience workforce, opportunities for more inclusive learning and professional development must be developed that enable all geoscientists to advance academically and professionally, including those living with disabilities.

The member societies of the American Geosciences Institute (AGI) are committed to promoting educational and career opportunities to all geoscientists through proactive efforts that engage individuals with disabilities and reduce barriers to full inclusion, in accordance with any relevant national regulations. Consequently, we, as the representative leadership of geoscientific professional societies and organizations, seek to embrace, empower, engage and sustain the participation and retention of individuals living with disabilities within all sectors of the geoscience community.

As an inclusive geoscience community, supportive of the needs of all current and future geoscientists, we agree to:

- Encourage the development of flexible learning environments and inclusive curricula, including in the classroom, laboratory, and field that are conducive to developing the skills of geoscientists of all physical, sensory, or cognitive abilities.
- Foster the participation and support the retention of geoscientists who live with disabilities in academic communities, our professional organizations, and the workforce.
- Promote accessible pathways for students with disabilities to transition into geoscience careers that maximize their unique perspectives, competencies, and abilities.
- As a representative society, ensure that career and professional development opportunities are made available to geoscientists with all abilities to support life-long growth, and by extension, promote inclusion and act as an example for other organizations.

Signatories (as of Spring 2018)

American Geosciences Institute Executive Committee
American Association of Petroleum Geologists
American Institute of Professional Geologists
Association for Women Geoscientists
Association of American State Geologists
Association of Earth Science Editors
Botanical Society of America
Clay Minerals Society
Council on Undergraduate Research - Geosciences Division
Geochemical Society
Geological Society of America
Geological Society of London
International Association for Promoting Geoethics
International Medical Geology Association
National Association of Geoscience Teachers
National Association of State Boards of Geology
National Cave and Karst Research Institute
National Earth Science Teachers Association
National Speleological Society
Paleontological Society
Palynological Society
Society for Mining, Metallurgy and Exploration
Society of Economic Geologists
Society of Independent Professional Earth Scientists
Soil Science Society of America

Web link: https://www.americangeosciences.org/community/disability-consensus-statement
Appendix B: Original GEOPATH Project Summary

*GP-EXTRA Engaging Students in Inclusive Geoscience Field Experiences via Onsite-Remote Partnerships*

**PIs:** Steven Whitmeyer, Christopher Atchison, Jennifer Piatek, Helen Crompton, Declan De Paor. **Other faculty:** Eric Pyle, Trevor Collins, Martin Feely

**Overview:**

The importance of field-based learning experiences in geoscience education has been well-documented through decades of geoscience field trip reports. However, learning in the field is not entirely accessible for students with physical disabilities. Recent initiatives suggest that traditional approaches to field education are likely to discourage students with disabilities (SWD) from pursuing programs that lead to geoscience careers. This proposed work will engage SWD in authentic field experiences via a peer instruction approach that pairs SWD with more physically capable students in collaborative field-based exercises. The principal anticipated long-term outcome of the proposed work is increased engagement and retention of SWD in the geosciences by instilling confidence in their ability to do authentic field research.

**Intellectual Merit:**

Two cohorts of undergraduate geoscience students will be recruited: one with mobility disabilities (SWD) and another without. Students from each cohort will be paired in a variety of field experiences and collaborate both on-site in the field and through remote connections. Field data collection and analyses will occur in real-time via web-linked tablets and other interactive mobile devices. Real-time video and audio communication, both student-student and student-faculty, will be facilitated through cutting-edge wearable technologies. The field program will incorporate a range of experiences that are traditionally included within an undergraduate
geoscience curriculum. These will include day-long field trips that focus on a specific set of field skills, such as generating strip logs for stratigraphic analyses, measuring structural orientations using a compass-clinometer, and mineralogical and petrologic analyses using a hand lens. Field experiences in year two will focus on more advanced, multi-day exercises that will require student teams to synthesize geologic field data collected into maps and reports that summarize the tectonic history of a region.

**Broader Impacts:**

This project focuses on issues of access and inclusion for students with mobility disabilities, however there are ramifications for other forms of disabilities. The traditional approach to field geology has been to treat condition, agility, and sight, among others, as course prerequisites. An alternative philosophy advocated here is that partnerships of students with diverse physical abilities, as well as student-instructor pairs, constitute a collective set of human senses and perspectives that can be as effective as individuals with no physical limitations. Outcomes from this work should apply to a wide variety of barriers to onsite field investigations that SWD and others may face during the course of their geoscience careers. Results and experiences from this project will be disseminated via presentations, peer-reviewed publications, and a capstone field trip for geoscience students, faculty, and professionals. During this trip, project participants (PIs and students) will demonstrate our methods for, and experiences with, engaging SWD in authentic field experiences. This work is anticipated to increase the probability of retaining and graduating geoscience SWD and other collaborating students, and encourage and empower them to pursue geoscience careers.
Appendix C: IRB Approval

4/14/2017

Anita Marshall
USF School of Geosciences
4202 E. Fowler Ave.
Tampa, FL 33612

RE: Expedited Approval for Continuing Review
IRB#: CR1_Pro000026373
Title: An evaluation of Traditional, Linked, and Virtual approaches to field-based learning, and a study of access and social climate for students with physical disabilities in the geosciences. Funded by NSF Award # 1540652

Study Approval Period: 5/10/2017 to 5/10/2018

Dear Ms. Marshall:

On 4/13/2017, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents contained within including those outlined below.

Approved Item(s):
Protocol Document(s):
Protocol_Marshall_FieldWorkAndDisability

Consent/Assent Document(s)*:
Consent form.pdf

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab on the main study's workspace. Please note, these consent/assent document(s) are valid until they are amended and approved.

The IRB determined that your study qualified for expedited review based on federal expedited category number(s):

(6) Collection of data from voice, video, digital, or image recordings made for research purposes.
(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with USF HRPP policies and procedures and as approved by the USF IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment. Additionally, all unanticipated problems must be reported to the USF IRB within five (5) calendar days.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John C. Schinka, Ph.D.
John Schinka, Ph.D., Chairperson
USF Institutional Review Board
Appendix D: Arizona Field Trip Site Descriptions

This Appendix contains site descriptions for the stops used during the first-year GEOPATH field trip to northern Arizona. It is not intended as a geologic field guide, but rather as a means of better understanding the student experiences from the first year. The first year of the GEOPATH project did not factor heavily in the research of the dissertation, mainly because the approach examined for this research, remote collaboration, was only briefly tested the first year. However, students do reference locations and events from the first year in interviews, and others may find this information useful in planning their own inclusive field trips. The description of each stop includes a short summary of the location, a description of the assigned student activities, and a brief summary of the accessibility of the site.

Stop 1. Sunset Point Rest Stop

Sunset point is a rest stop on I-17 about an hour north of Phoenix Sky Harbor Airport. The scenic overlook has excellent views of the Bradshaw mountains; which are composed of fault blocked, mineralized Precambrian rocks (Garry & Bleacher, 2011). On the other side of the highway from the rest stop is a small shield volcano called Joe’s hill. Rocks from Joe’s Hill lava flows are found throughout the landscaping along the paths at the rest stop. Students received an introductory talk about the geologic regions between Phoenix and Flagstaff, and some of the visible features from the overlook. Some nice large samples of vesiculated basalts are right next to the sidewalk at the rest stops and provide a first exposure to some of the volcanic rock textures that students would encounter later in the trip. This was primarily an orientation stop, so there was no student assignment to turn in.
This is a fully accessible stop with excellent paved walkways leading out to fully accessible overlooks. There are also restrooms, vending machines, and a fully accessible shaded picnic area.

Figure D 1. Walkway leading to overlook at Sunset Point Rest stop. D2. The large scenic overlook. D3: panoramic view from the overlook. All photos in Appendix D by A. Marshall for the IAGD & NSF GEOPATH grant #1540652 unless otherwise noted.

Stop 2. Slide Rock State Park

Located 10 miles north of Sedona on Hwy 89A in Oak Creek Canyon. The park provides excellent views of the stratigraphic sections exposed on both sides of the canyon. The park is located on the west side of the canyon and has a paved trail that runs 350 meters south-north from the parking lot to an overlook of the park’s namesake feature; a river flowing over an eroded sandstone unit that is used as a natural waterslide by park-goers. The canyon width ranges from 150-250 m, and most of the stratigraphy is observable from a distance from the trail or parking lot. Some units along the river bed can be partially observed from an accessible overlook, or directly accessed by a steep stair case. The lower-most stratigraphic units, some with excellent cross-bedding, are only visible from the river bank. However, a short, easy trail
runs along the top of the bluff beyond the accessible overlook to some much better views of the lower units. This trail requires a step up or down of about 6 inches in two places, but is otherwise an easy walk.

The learning assignment at Slide Rock was to describe the stratigraphy of each side of the canyon, calling attention to notable differences in the west and east sides. Students worked in assigned pairs, one from the SWD cohort and one from the SWoD cohort. Data was collected on digital tablets which utilized apps specifically designed for building and describing stratigraphic columns. Each pair could decide to stay together or have one member go down the stairs to the river to document the lower-most units. After work time was up, the group met for a faculty-guided discussion about student observations and possible interpretations.

Figure D4. Paved path through Slide Rock State Park. D5. View of a portion of the west side of the canyon wall from the sidewalk.
Stop 3. The Trail of Time, Grand Canyon:

The Trail of Time is a unique exhibit along 4.56 km of the South Rim of the Grand Canyon between Grand Canyon Village and the Yavapai Geology Museum (see description in Karlstrom et al., 2008). Each meter of the trail represents one million years of time. Along the route, markers and interpretive signs point out features in the canyon. The trail has large samples of the rock units that correlate to the time markers on the trail.

Students were assigned to construct their own digital stratigraphic column using specialized apps on their tablets using the rock samples, markers and interpretive signs along the trail. Students were assigned partners but in practice, grouped up into informal teams or broke off alone as the day progressed and varying endurance levels spread out the group.

The entire route is considered accessible, but it does have some notable hilly sections which may require assistance for manual wheelchairs and may cause issues for some types of mobility-related disabilities. Caution should be exercised when planning the use of this location in terms of weather and timing. There are limited benches, limited shade, and no place to refill...
water bottles between the start and end points. Due to the layout of the trails, there were no options for exiting the exercise when participants with disabilities became fatigued, so all participants had to complete the entire route on foot. This greatly extended the amount of time needed to complete the exercise and left several students in compromised physical states for the following field day. There is a service road that allows access to the halfway point, and it is recommended that organizers work with park officials to make use of this access point for future trips.

![Image of the start of the Trial of Time on the South Rim of the Grand Canyon.](image1.jpg)

![Image of an interpretive sign along the trail.](image2.jpg)

![Image of students examining a rock sample on the side of the Trail.](image3.jpg)

![Image of brass markers like this one along the route illustrate geologic time.](image4.jpg)

**Figure D10:** The start of the Trial of Time on the South Rim of the Grand Canyon. **D11:** An interpretive sign along the trail. **D12:** Students examine a rock sample on the side of the Trail. **D13:** Brass markers like this one along the route illustrate geologic time.

**Stop 4. Sunset Crater National Volcanic Monument:**

Sunset Crater is a basaltic cinder cone, and the youngest vent in the San Francisco Volcanic Field at approximately 1,000 years old (Priest et al., 2001). It is managed by the US Forest Service as a National Monument. Prior to the park entrance, a short stop at a turnout on
the road to the park provided an excellent view of San Francisco Peaks and Sugarloaf Mountain for a discussion of the sector collapse of SF Peaks, and the mixed eruptive history of Sugarloaf Mountain. Once inside the park, there are many trails through the lava flows and smaller cinder cones. The Bonito Vista trail offers both accessible and inaccessible trails through many interesting lava flow features. The Bonito Lava Flow trail on the south side of the road is paved and has accessible restrooms in the parking lot. The south side trail also provides good view of Sunset and Lenox Craters. The Bonito Lava Flow trail on the north side of the road has a series of short unimproved trails of varying terrain through the lava flow. The trail surface is a layer of loose, fine scoria gravel 10-30mm thick, which may cause issues for some types of mobility impairments. After time at the Bonito Flow, a quick stop at the Cinder Hills overlook provided a good location to discuss the numerous crater visible within the park, and other features of the SFVF as some craters in the far eastern side of the SFVF can be seen in the distance.

The assignment at Sunset Crater was to document unique features in the lava flows and cones that may lend insight into the eruptive events that formed these two volcanoes. Students were assigned pairs and were encouraged to split up to cover more ground and test out the communication technology. The technology used for this exercise included the tablets for data collection and notes, radios for audio communication and one wearable camera, which students took turns using. There was not enough cell service for video calls or live photo sharing, so the approach to collaboration was “scout and report”; split up, gather data, come back together to share the data.
Figure D14 (top left, then clockwise) View of the San Francisco Peaks from the turnout on the entrance road to the park. D15 The Bonito Lava Flow accessible trail offers excellent opportunities to examine a variety of lava flow features up close.

Figure D16. The trail surface of the northern section of the Bonito Lava flow trail. D17 Students exploring the lava flow while talking with partners via hand radios.

**Stop 5. Wupatki National Monument**

The lunch stop after Sunset Crater was the adjacent Wupatki National Monument. Students were given time to eat and explore the native ruins and spectacular views of the painted desert. Temperatures were very warm, and the air-conditioned visitor center provided a good resting place for those that needed it. There was no assignment at this stop. However, this stop seemed to be an important one for social connections, as it offered the first significant segment of unstructured time in the schedule. It is important to note that wheelchair-friendly trails are limited to a short distance down from the visitor center. Further exploration is possible with assistance on steep hills.
5. SP Crater:

SP Crater is a basaltic cinder cone volcano, located in the north-central portion of the San Francisco Volcanic Field. It is notable for a large and distinctive lava flow emanating from the base on north side of the cone. SP Crater was the location chosen to test out the remote collaboration approach to field work using live video streaming. This location played a significant role in the student’s interview responses at the end of the field trip, and directly influenced the way the following year’s field trip was planned. Some parts of the lava flow are accessible by dirt road, but the entirety of the cone is accessible only by hiking. It is important to note that accessible vans with low clearance may not be able to drive all the way to the base of the cone due to road conditions. The road and the volcano are located on a privately-owned ranch and permission was obtained before the start of the field trip.

Figure D18. SP Crater as viewed from the access road. D19. The lava flow at SP crater.

The plan was for the more able participants to climb the volcano and document what they saw along the way and communicate that information back to the base team. Then during the more challenging part of the hike towards the top, the base team would move the vans to a road that directly accesses the lava flow for an on-the-ground examination, while collaborating with the students at the top with an overhead view. Faculty members with expertise in SP crater and the SFVF would guide discussions from the base camp using the video link.
All students were given the option of attempting the hike or staying at the “base camp” (vans). The accessible vans were parked about 600 meters south east from the base of the cone, which was as close as the road conditions would allow. One hiking group set off from that point to hike straight up the steep side of the cone. The other hiking group moved a van around to a trail head on the southwest side of the cone. The distance from the base station (the accessible vans) to the top of the crater rim was approximately 1,100 meters. For most of the hike, distance and obstruction from the volcano prevented communication between the base camp and either hiking team. Communication between each hiking team was also not possible because they were climbing different sides. Even members of the same team that had gotten spread out during the climb had only intermittent signal.

The lack of communication between any person on the volcano and the base team was logistically problematic. The base team did not know where the hikers were, or if the second part of the plan (moving the vans) should be done or not. The result was that the base team had no constructive activity to do while waiting. This was a source of frustration and worry for the base team. Eventually, communication was re-established once the teams made it to the top. The video connection was weak, however, and had a 1-2-minute delay. Hand radios were used for audio communication. With the spotty and slow video feed, it was only used for about 10 minutes. Yet that 10 minutes was highly encouraging to the participants and gave everyone confidence that a better result could be achieved in the following year’s field trip.
Stop 6. Meteor Crater

Barringer Meteor Crater is a large impact crater in the desert 40 miles east of Flagstaff, AZ. It is privately owned and there is a fee to enter. There is an excellent museum on the crater rim with a panoramic window overlooking the crater. A tour of the rim is accessible and allows some closer views of the stratigraphy of the upper part of the crater. No tours are allowed in the bottom of the crater. The stratigraphic assignment could be completed from the window view from the museum or from the rim trail.
Figure D24. The visitor’s center at Meteor Crater. D25. The view of the Crater from the visitor’s center. D26. The tour of the rim is accessible, but for students who were struggling in the heat, D27. the air-conditioned interactive museum/overlook was an excellent (and according to participants, more informative) option.

Stop 7. Montezuma’s Well

Montezuma’s Well is a karst sinkhole lake in the Verde Limestone formation located 45 miles south of Flagstaff in the Verde Valley. The sinkhole lake is fed by a massive freshwater spring (Garry & Bleacher, 2011). Built into the walls of the sinkhole above the lake are ruins built by the Sinagua people. The sinkhole lake drains through a limestone fracture to feed a stream lower in the valley. The lower stream creates a natural oasis that is often more than 20 degrees cooler than the parking lot at the rim of the sinkhole.
There is a trail to from the parking lot to the rim of the sinkhole that is marked “accessible” but has a section that is far too steep for most wheelchairs, even with assistance. Ironically the non-accessible trail is more accessible up to a step-down right at the overlook. The only access to the lower oasis is down a steep and winding stone staircase. Students used a “gather and report” style of documentation to document the oasis for teammates who could not access it. Another app for live streaming was tested briefly at this location, but the resolution was too low to be useful. This was a short stop due to scheduling and heat.
Figure D31. The steep rock staircase leading down to the lower oasis area. D32. The lower oasis area as viewed from the base of the staircase (photo by student participant). D33. The canal in the lower oasis area. D34. A park ranger takes participants into a fracture to view basalt inclusions in the limestone wall.

Appendix D References:


Appendix E: Social Presence Survey

The Sociability Scale modified for use in this study was modified from Kreijns et. al, (2007).

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<td><strong>1. This approach enables me to easily contact my team mates.</strong></td>
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<td><strong>2. I do not feel lonely or isolated with this approach</strong></td>
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<td><strong>3. This approach enables me to get a good impression of my team mates, even when they are not physically present.</strong></td>
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<td><strong>5. This approach enables us to develop into a well-performing team.</strong></td>
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<td><strong>6. The approach enables me to develop a good working relationship with my teammates.</strong></td>
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<td><strong>7. This approach enables me to identify myself with the team.</strong></td>
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<td><strong>8. I feel comfortable with this approach</strong></td>
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<td><strong>9. This approach allows for non-task related conversations</strong></td>
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<td><strong>10. This approach allows me to make close friendships with my team mates.</strong></td>
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**Open-ended questions:**

11. Was there something about this approach that made you feel isolated or not a part of the team?
12. What was something that made this approach especially valuable in terms of team-building or social inclusion?

Figure E1. The Social Presence survey used in this study. Items 1-10 ask participants to rate each statement on a scale of 1-5 (1 = disagree strongly, and 5= agree strongly). Items 11 and 12 provided text boxes for free responses.
Appendix F: Interview Prompts

At the end of each field trip, interviews were conducted with the participants. At the end of the first field trip, a whole-group interview was conducted with all students, faculty, and staff present and participating. At the end of the second field trip, student participants were interviewed in focus groups by cohort (SWD and SWoD) and no faculty were present besides those facilitating the interview. The following prompts are transcribed exactly as they were given to the participants during the interviews and were not crafted by the researcher.

Year 1 Whole Group Interview Prompts:

1. Inclusiveness, talking about that it was one of the major goals, how did that work? Ok?
2. How did technology contribute to this week’s program in 3 ways: data collection, communication, and inclusion?

Year 2 Focus Group Interview Prompts:

1. Thinking about this Ireland experience, what is the most important thing you’ve learned about fieldwork in the geosciences.
2. Describe your perspective of social, academic and physical inclusion during this trip. Social is the community; academic is the learning at your current level; and physical is the inclusion according to your needs and abilities. Community is the pairings, small groups, whole group.
3. Speak to the use of technology to achieve our goals of this project – how has technology supported your leaning during this trip?
Appendix H: STROBE Observation Protocol

For each 5 minutes of video (called a cycle), a total of 4 observations are made. Each observation is about 10-15 seconds long. It is up to the observer(s) to determine when to take observations within each cycle – evenly spaced, at random, with a timer, etc. It is best for observation verifications that the observer note the start time of each observation. For each observation, the observer chooses which of the following 4 categories best describes the student’s actions: academic engagement, social engagement, technical engagement, or disengaged (see Table 3.1 for descriptions).

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Appendix G: Volcanology Research

Note to reader: The following paper was published in the Journal of Volcanology and Geothermal Research and is reprinted here with permission from Elsevier.

The Geoscience Education PhD program at USF requires research in some other aspect of geology. In my first semester at USF, a field trip took me to the San Francisco Volcanic Field (SFVF) in northern Arizona. Our field site for the week was Rattlesnake Crater, a mixed phreatomagmatic/magmatic eruption site on the east side of the SFVF. Volcanology was not my background, but I became fascinated with the location and wanted to understand more about how these types of volcanic craters were formed. Three years of immersion in volcanology research produced the following publication, originally published in the Journal of Volcanology and Geothermal Research (Marshall et al., 2015). Follow-up research was conducted at two other phreatomagmatic vents in the SFVF was funded by a grant from GSSI Inc., which is described in Marshall, Kruse, Macorps, & Charbonnier, 2015.

The numerous field trips undertaken with the volcanology group provided opportunities to examine how different field trips were designed and executed. It became clear that both applied geophysics and volcanology have great potential to provide opportunities for inclusive field research projects if learning exercises were approached in an inclusive manner.

Creating opportunities for scholarly research in geoscience specialty fields with students of diverse abilities is an important component of changing the culture of the geosciences. Many career geoscientists will never read a single publication regarding geoscience education, but a research paper or poster presented at a conference by a diverse student group provides a mechanism for inclusion in the research communities that drive the cultural tone of the geosciences. I hope to continue this line of research in the future by developing collaborations across geology specialty fields that allow the integration of specialized field research in topics such as volcanology and geophysics with inclusive approaches to field learning.

Appendix A References:


Subsurface structure of a maar–diatreme and associated tuff ring from a high-resolution geophysical survey, Rattlesnake Crater, Arizona

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ABSTRACT
Geophysical survey techniques including gravity, magnetics, and ground penetrating radar were utilized to study the diatreme and tuff ring at Rattlesnake Crater, a maar in the San Francisco Volcanic Field of northern Arizona. Significant magnetic anomalies (+1600 nT) and a positive gravity anomaly (+1.4 mGal) are associated with the maar. Joint modeling of magnetic and gravity data indicate that the diatreme that underlies Rattlesnake Crater has volume of 0.3–1 km³ and extends to at least 900 m depth. The modeled diatreme comprises at least two zones of variable density and magnetization, including a low-density, highly magnetized unit near the center of the diatreme, interpreted to be a pyroclastic unit emplaced at sufficiently high temperature and containing sufficient magmatic fraction to acquire thermal remanent magnetization. Magnetic anomalies and ground penetrating radar (GPR) imaging demonstrate that the bedded pyroclastic deposits of the tuff ring also carry high magnetization, likely produced by enefatic emplacement of hot pyroclastic density currents. GPR profiles on the tuff ring reveal long (~100 m) wavelength reflections in bedding planes. Elsewhere, comparable bedforms have been interpreted as base surge deposits inflated by air entrapment from eruption column collapse. Interpretation of these geophysical data suggests that Rattlesnake Crater produced highly energetic phreatomagmatic activity that gave way to less explosive activity as the eruption progressed. The positive gravity anomaly associated with the maar crater is interpreted to be caused by coherent bodies within the diatreme and possibly lava ponding on the crater floor. These dense magnetized bodies have excess mass of 2–4 × 10¹⁰ kg, and occupy approximately 5% of the diatreme by volume. Magnetic anomalies on the crater floor are elongate NW-SE, suggesting that the eruption may have been triggered by the interaction of ascending magma with water in fractures of this orientation. GPR imaging of the tuff ring also suggests that substantial land-slip may have occurred on the western rim, perhaps causing part of the tuff ring to collapse into the crater. Strong radar reflections indicative of well-developed weathering horizons are present as well. The techniques employed at Rattlesnake Crater demonstrate the value of combining multiple geophysical techniques in areas where exposures are limited and invasive exploration is not an option.

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Introduction
Explosive phreatomagmatic volcanism creates risk for the millions of people that live within active volcanic fields around the world (Chester et al., 2000). These eruptions occur when rising magma and groundwater interact, and can produce craters 1–2 km in diameter and more than 300 m deep (Wohletz and Sheridan, 1983; Lorenz, 2003; Lorenz and Kurschusko, 2007; Valentine and White, 2012). The excavation of such craters, or maars, may result from one explosion or many, and the length of time between eruptions is highly variable (White and Ross, 2011). Geophysical survey methods provide valuable data about diatremes and related sub-surface features associated with maars, which greatly augment what we can observe on the surface and contribute to our understanding of the structure and eruptive mechanisms of phreatomagmatic vents (Schulz et al., 2005; Melina et al., 2009; Blakie et al., 2014). Here we present new geophysical surveys and forward models of the sub-surface structure for Rattlesnake Crater, one of many phreatomagmatic eruption sites in the San Francisco Volcanic Field (SFV) of northern Arizona, USA.

Maar craters are underlain by diatremes that contain pulverized country rock and juvenile material produced during the eruption (White and Ross, 2011; Valentine and White, 2012). The top of the diatreme is generally assumed to roughly coincide with the diameter of the surface crater, although the shape of the crater can change significantly due to syn-eruptive and post-eruptive processes such as faulting, mass wasting, subsidence, and in filling by sediments (White and Ross, 2011). Previous geophysical surveys reveal that some maar–diatremes

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have complex structures that are not evident on the surface, including multiple eruption points, igneous dikes, buried lava lakes, faults and subsidence features (Schultz et al., 2005; Millena et al., 2009; Blakie et al., 2012; Bolos et al., 2012).

Surrounding the crater, a tuff ring made of ejected material forms a rim around the eruption site. Examination of the tuff ring can yield valuable information regarding magma volatile content and composition, and the duration of an eruption (Chough S.K., 1990; Sohn and Park, 2005; Brand and Clarke, 2009). Observations of erosional surfaces within tuff rings are used to infer the number of eruptive phases a vent may have produced, and the duration of repose between them (McPhie et al., 1990; Zimmer et al., 2010). Analysis of exposed deposits can also be used to estimate eruptive energy (Vazquez and Orr, 2006; van Otterlo and Cas, 2013). However, many stratigraphic studies of phreatomagmatic sites are limited by the availability of exposed units in outcrop.

Utilizing gravity and magnetic surveys is a well-established approach to studying phreatomagmatic eruption sites (Cassidy et al., 2007; López Loera et al., 2008; Millena et al., 2009; Bolos et al., 2012; Skjærvø et al., 2012). Similarly, GPR has been widely utilized in studies of volcanic tephra and surge deposits (Russell and Stasicki, 1997; Gómez-Oritz et al., 2005; Gómez et al., 2008; Krane et al., 2010; Courtland et al., 2012, 2013), and of phreatomagmatic deposits (Cagnolli and Uye, 2001). In this paper, we use all three techniques to constrain the geometry, volume, and facies of the diatreme beneath Rattlesnake Crater and its tuff ring.

**Rattlesnake Crater and the San Francisco Volcanic Field**

The SPVF of northern Arizona is an active volcanic region containing more than 600 volcanic cones within 4,700 km² (Prest et al., 2001). The SPVF is a Colorado Plateau field (Condit et al., 1989), and the focus of activity within the field has shifted from west to east with time, reflecting the motion of the North American Plate (Tanaka et al., 1986). The SPVF is bimodal, but most volcanic vents erupt basalts (Prest et al., 2001). There are at least 12 vents that show evidence of phreatomagmatic activity within the SPVF; many of these sites have complex or mixed eruptive histories.

Rattlesnake Crater is a basaltic maar and tuff ring located in the southeast region of the SPVF (Fig. 1). The crater is elongate, approximately 1.4 km in diameter on the long axis, in a NW-SE direction. The tuff ring surrounding the crater varies in height from approximately 60 m on the NE side to only a few meters high on the SW side, and is obscured on the SE side by an overlapping scoria cone, called Rattlesnake Hill. The presence of tephra from Sunset Crater (Orr et al., 2008), and the Brunhes-age magnetic orientation associated with Rattlesnake Hill lavas (Tanaka et al., 1986) place the age of Rattlesnake Crater between 600 and 780,000 yr BP.

Rattlesnake Crater is constructed on top of substantial lava flows, tens of meters thick that crop out in the area surrounding the tuff ring. Based on coring in the area, the sub-surface stratigraphic column comprises Plio-Pleistocene sedimentary units identified in descending order as the Kaibab, Toroweap, Coconino, Schnebly Hill, and Supai Formations (Hoffman et al., 2006). The uppermost stratigraphic unit, the Kaibab Formation, is a fractured (Gettings and bulbman, 2005) and kaolinitic (Montgomery and Harshbarger, 1992) Permian limestone with a maximum thickness of 200 m in the area. Underlying the Kaibab, the Toroweap Formation, a mixed variety of near-shore elastic units, is less than 100 m thick. The Coconino Sandstone, a sequence of cross-bedded fine-grained sandstone 400-500 m thick, is the primary water-bearing unit. The thin (tens of meters) Schnebly Hill Formation both interfingers with and underlies the Coconino and is made up of very fine-grained mudstones, limestone and dolomite units. The well logs of Hoffman et al. (2006) and in the Supai Formation, sometimes grouped with a number of lower units as “Red beds,” which are a collection of distinctly-colored alternating units of sandstone, siltstone and mudstone.

The entire tuff ring is covered by weathering products and fall deposits, with the important exception of a band of outcropping units

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**Fig. 1.** Data acquisition locations for the geophysical study of the Rattlesnake Crater complex (blue star, inset), one of hundreds of volcanic vents (red dots, inset) within the SPVF, Arizona. The complex includes Rattlesnake Crater, a maar surrounded by a tuff ring and bounded to the SE by Rattlesnake Hill, a scoria cone. White lines show the track of the ground magnetic survey (Fig. 3); black dots indicate gravity survey points (Fig. 2), and yellow lines indicate the locations of GPR profiles. The green box shows the map extent of the contoured magnetic anomaly map. Map Coordinates are in UTM, zone 12. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
on the inner wall of the NE side of the crater (Fig. 1). This outcrop comprises a section of the upper ring, approximately 650 m in length, with maximum outcrop thickness of 20 m. At its widest point, the outcrop roughly follows the shape of the crater rim, then diverges downslope to the west before pinching out midway down the inside slope of the crater wall. Valentine (2012) identified a possible unconformity in the tuff ring outcrop containing basaltic fragments that may indicate the main and the scoria cone formed concurrently, but the source of these fragments is uncertain and they may be from underlying lava flows. Xenoliths from lower Coccino and Redbed units are more abundant in the top-most layers of the tuff ring suggesting progressive deepening of explosions inside the main diatreme (Valentine, 2012). Nevertheless, the utility of geological field mapping is limited by the lack of exposures. Furthermore, the area is protected because of the presence of archaeological sites. Remnants of protected native encampments, found on both the flanks of the scoria cone and the tuff ring, rule out the possibility of trenching or similar approaches to investigate the underlying deposits in and around the crater. Gravity, magnetic and GPR surveys allow us to study the structure of the diatreme beneath the crater as well as the internal structure of the tuff ring in a noninvasive fashion.

Structural influences

Understanding structural controls on distributed volcanism is important in order to assess the potential distribution of future events, the tectonic conditions that give rise to distributed volcanism and the sequence of events during individual eruptions. Indications of structural controls can include the position of some vents on or near faults (Riggs and Buffiefield, 2003; George et al., 2015), development of vent alignments parallel or slightly oblique to fault zones (Guffanti et al., 1990; Aranda-Gómez et al., 2003), and the development of vent alignments parallel to joint sets or other tectonic fabrics (Delaney and Gartner, 1992; Neumeister et al., 2003; Castelli and Koch, 2010; Kiyosugi et al., 2010; Re et al., 2015). There is abundant evidence in the SFV that volcanism migrates along faults (Conaway et al., 1987; Reddick in the region surrounding Rattlesnake Crater is highly fractured, with orientations mainly to the NW and SW (Gettings and Ruhlman, 2005). Fractures are assumed to be the primary groundwater recharge mechanism for the Coccino Aquifer, and produce significant water yields to wells in otherwise impermeable stratigraphic units (Montgomery and Haribarger, 1992; Hoffman et al., 2006).

Geophysical techniques

Gravity and magnetic data can be used individually or combined with data from other surveys to constrain the subsurface structure and to infer the characteristics of the subsurface. In particular, gravity data are useful for identifying the location of the magma chamber, while magnetic data can provide information about the presence of ferromagnetic materials. In this study, gravity and magnetic data were collected to infer the subsurface structure of the Rattlesnake Crater. The gravity field was modeled using a digital elevation model (DEM) to correct for topographic effects. The magnetic field was modeled using a finite-difference method to calculate the magnetic anomalies over the study area. The resulting magnetic and gravity maps were then used to interpret the subsurface structure of the Rattlesnake Crater.
the tuff ring where terrain allowed, roughly 150–200 m apart. Magnetic data were not collected on the steepest parts of the tuff ring or on the slopes of Rattlesnake Hill. Along collection lines, sample spacing was approximately 1 m, and a total of 72,437 magnetic measurements were collected.

The positions of magnetic readings were retrieved by matching the time stamp records of the magnetometer and GPS data loggers. Sensor dropouts and spikes in the data were removed by setting a maximum allowable change in neighboring magnetic readings (1 m apart) to ±8 mT, and removing points that create a slope greater than 30 mT/m from the dataset (George et al., 2015). The regional total magnetic field strength, based on the international geomagnetic reference field (IGRF), was subtracted from each day's data before combining with other survey results.

After processing, data reproducibility was assessed by comparing all line crossings. Line crossings were defined as magnetic readings taken less than 5 m apart on the ground and separated by more than 30 min in time (George et al., 2015). The mean difference among the line crossings in our survey is 0.48 mT with a standard deviation of 167 mT. The standard deviation of 167 mT is a result of very high localised magnetic gradients within the survey area, produced by volcanic and intrusive bodies buried in the shallow subsurface. As expected, we found that line crossing errors were greater on steeper terrain, probably due to the position of the sensor with respect to the slope. We note that survey error, expressed as the standard deviation at crossing points, is <10% of the total magnetic data range.

The magnetic map was filtered by upward continuation to aid in interpretation of magnetic anomalies. This technique uses a mathematical filter to attenuate the influence of shorter wavelength anomalies. In effect, this results in a map that appears as if it were the topographic surface. Data from the first survey was upward continued 2 m before being combined with data from the later survey to account for a difference in sensor heights between the two surveys. The combined data was then interpreted to a grid with 10 m spacing. Two upward continuations were performed. A 5 m continuation shows the data with all but the very shortest wavelength anomalies, which are typically caused by surface noise such as individual pyroclasts. A 50 m continuation produces a map that illustrates anomalies with wavelengths typically associated with material tens of meters below the surface.

**GPR data collection and processing**

Two GPR profiles were collected on the tuff ring surrounding Rattlesnake Crater (Fig. 1). Profile 1 extends 500 m over the west side of the tuff ring and part of the crater floor on the shorter, more gently sloping side of the tuff ring where there are no outcrops. The data were acquired with 50 MHz unshielded antennae spaced 2 m apart and moved by manually repositioning the antennae every meter along the survey line. Profile 2 traverses 325 m of the outer slope of the steeper side of the tuff ring and was acquired with a 250 MHz shielded antennae pair pulled on a sled.

Data were processed with the software package ReflexW using a dewow filter, time zero adjustments, and uniform linear gain adjustments. Profile 1 was migrated with a uniform velocity diffraction stack migration. The profiles were then corrected for topography. Analysis of diffraction hyperbolas indicates the radar velocity was approximately 0.13 m/ns and relatively uniform along both profiles over the 0.5-10 m depths of the reflecting horizons. This velocity was used to migrate the 50 MHz data, to convert time to depths, and to correct for topography.

At the 0.13 m/ns velocity, the center frequency of the 50 MHz pulse corresponds to a wavelength of ~2.6 m; that of the 250 MHz pulse to ~50 cm. Thus the radar wavelengths are longer than the thickness of most individual beds observed in the tuff outcrop. Vertical resolution can be characterized as approximately one fourth of the radar wavelength (Gada et al., 2005). Thus, horizons in a radargram will capture the altitude of beds, but there may not be a one-to-one correspondence between radargram returns and subsurface contacts. Lower frequency antennae, like the 50 MHz used to collect Profile 1, provide greater depth penetration, but lower spatial resolution. Conversely, the 250 MHz antennae used to collect Profile 2 provides lower spatial resolution, but with much less penetration into the subsurface.

**Geophysical anomalies and their interpretation**

**Gravity anomalies**

An overall positive gravity anomaly was detected within Rattlesnake Crater. The gravity data have an overall range of 1.4 mGal with maximum positive amplitude near the center of each profile line. The positive anomaly extends over the entire crater on the W-E profile line and over a portion of the crater in the S-N direction (Fig. 2). This positive anomaly is the result of denser material in the subsurface in the crater area relative to the undisturbed sections outside the crater. On the W-E profile, a significant gravity low (~0.7 mGal) correlates with the location of the tephrara ring on the E side of the crater. Elevated gravity readings just outside the tephrara ring on both sides of the crater on the W-E profile coincide with lava flows surrounding the crater. On the S-N profile, the highest gravity readings are near the center of the crater, and drop off sharply on the N end of the crater. The low gravity readings near the N end of the S-N profile may be a result of the low density material in the tephrara ring. A low related to the tephrara ring on the west side of the crater may be masked by the proximity of lava flows from Rattlesnake Hill. Our attempts to collect gravity measurements on the north side of the tephrara ring, which is steep and densely vegetated, were unsuccessful, so the S-N measurements do not continue past the crater to the north. There is no tephrara ring exposed on the southern end of the S-N profile; the gravity signature on the southern end is a result of traversing deposits from Rattlesnake Hill.

**Magnetic anomalies**

The magnetic map (Fig. 3) reveals anomalies associated with mapped features, and others that do not correspond with features visible on the surface, which are interpreted to be the result of subsurface structures. The primary magnetic anomaly is the center of the map corresponds to the crater and has an area of about 0.48 km² (Fig. 3, Letter A). The highest amplitude region inside this central anomaly (+ 1600 nT) is elongate NW-SE, parallel to the long-axis of the maar. The strongly positive magnetic anomaly to the south of the crater corresponds to a positive anomaly in the summit rim of Rattlesnake Hill (Fig. 3, Letter B). In the SW quadrant of the map, a band of positive anomalies extends to the edge of the survey area, and has no corresponding surface feature (Fig. 3, Letter C). On the west side of the map, a contoured pattern of weaker anomalies cover the area between the tuff ring and the edge of the survey area (Fig. 3, Letter D). Wrapped around the central crater anomaly, a roughly horseshoe-shaped positive anomaly corresponds to the tuff ring (Fig. 3, Letter E). Along the SW section of the tuff ring, anomalies E and F become difficult to distinguish from one another. The trend of negative readings in the northern part of the map generally follows the pattern expected for the dipole signature of normally magnetized material in the northern hemisphere. The trend is even more apparent on the 50-m upward continuation of the magnetic anomaly map (Fig. 4).

The magnetic anomaly mapped as Feature A in Figs. 3 and 4, is paired with the coincidence of a positive gravity anomaly (Fig. 2) and indicates the presence of dense, highly magnetized material within the diatreme. Feature A is within the map area of the crater, with the exception of the NW section. In the NW, the anomaly extends beneath the base of the inner...
Fig. 2. W-E (top) and S-N (bottom) gravity profiles crossing Rattlesnake Crater. Solid black circles show the complete Bouguer gravity anomaly (mGal); circle with symbol shows gravity measurement at a single shared point between the two profiles. The brown-shaded area shows topographic elevation (m) measured by total station and GPS during the survey. See survey map (Fig. 1) for profile locations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 3. Magnetic anomaly map of Rattlesnake Crater and surrounding area. Magnetic data (thin white lines; see also Fig. 1) were interpolated to a grid and filtered by upward continuation to 5 m. The geological sketch (in black) shows the tuff ring rim (solid line with dot), break in slope at the base of the tuff ring (dashed line) and the trace of the topmost exposure of the subsurface layer (thin line on the inside rim just below the Label B). The solid outline on the southeast of the tuff ring is the break in slope at the base of Rattlesnake Hill. Black dots are Rattlesnake Hill vent locations. A third vent outside the map boundaries is not shown. Areas of interest include: A, the primary anomaly beneath Rattlesnake Crater; B, the rim of Rattlesnake Hill; C—a linear anomaly with no surface expression; D—a region of nested short wavelength anomalies; E—the anomaly associated with the tuff ring.
debris apron of the tuff ring. Morphologically, the shape of the tuff ring is broader and less steep at this location compared to the rest of the tuff ring. It may be that the inner wall of the western section of the tuff ring has collapsed, shifting material from the wall further into the crater on the NW side. This could also explain why the outcropping unit on the NE section of the inner wall (drawn on Figs. 3 & 4 just below the letter E) is not present in outcrop on the NW side. Feature A is modeled as an intrusion (or intrusions) within the diatreme and a shallowly-buried lava flow within the crater (Fig. 5).

The large anomaly SE of the crater represents the positively magnetized material of Rattlesnake Hill (Figs. 3 & 4, Letter B). Our survey of Rattlesnake Hill was limited by topography to the lower flanks and one transect across the top, so the anomaly shown is an incomplete representation of the magnetic signature of the volcano.

A nearly continuous band of positive magnetic values west of Rattlesnake Hill can be seen on both versions of the magnetic map (Figs. 3 & 4, Feature C). Feature C most likely represents a lava flow. Its strong signature in the 5 m upward continuation (Fig. 3) indicates the top of the flow must be relatively close to the surface. It is also evident on the 50 m continuation (Fig. 4), so the flow must be relatively thick; at least tens of meters. A nearby outcropping lava flow, assumed to be from Rattlesnake Hill, has a measured thickness of 21 m (Harburger, 2014). Other basaltic flows in the SVP have measured thicknesses of more than 30 m (Harburger, 2014), so a flow tens of meters thick is plausible. This lava flow is not evident on the surface by outcrop or topography, but may be part of a flow that outcrops on the west side of Rattlesnake Hill.

An area of mottled, short-wavelength anomalies extends along the west side of the survey area (Fig. 3, Feature D). Some of these anomalies correlate to small lava outcrops on the side and near the base of the tuff ring. These anomalies strongly attenuate as a result of 50 m upward continuation (Fig. 4), suggesting they result from very shallow bodies, most likely just beneath the surface. Field observations were inconclusive in determining the stratigraphic relationship between this lava flow and the tuff ring. These small lava outcrops could be clastogenic in origin, relating to an episode of fountaining, or these flows may come from a buried vent beneath the tuff ring, as small buried vents have been documented under maar deposits at other pheonotephritic sites in the SVP (Valentine, 2012). Alternatively, this flow may connect to the flow marked as Feature C to the south (Fig. 3), though there are substantial differences in the amplitude and wavelength of these anomalies in the magnetic data.

The entire rim of the tuff ring has a positive magnetic signature (Figs. 3 & 4, Feature E). The highest amplitude magnetic anomalies are on the NE section and coincide with the tallest part of the rim. Many tuff rings have little to no magnetic signature due to the random orientation of pyroclasts deposited below the Curie temperature. There are two possible explanations for the magnetic signature of the tuff ring. One possibility is that at some point during the eruptive history, magmatic eruption activity deposited spatter or other basaltic material around the crater. This is the case at other pheonotephritic vents in the SVP such as Colton Crater and Red Mountain (von Kooten and Basseck, 1978; Riggs and Duffield, 2008). The other possible explanation is that the magnetic signature is from the pyroclastic material which makes up the tuff ring itself. Tephra packages emplaced rapidly and in sufficient thickness could maintain enough heat after deposition to produce significant TRM. The positive magnetic signature of the tuff ring is inferred to be strongest along the rim because the inner and outer slopes of have undergone significant weathering. Slope failure could also cause a random orientation to the magnetically oriented clasts.

Gravity and magnetic modeling

Model properties

Gravity data and magnetic data collected along the E-W gravity profile were used to create two forward models of the maar–diatreme.
Magnetic data were modeled as the apparent magnetization resulting from thermally magnetized diatreme fill and tuff deposits, remnant magnetization of intrusions within the diatreme, and lava flows near the surface (Fig. 5).

Forward models were created using OASIS Montaj and Gm-Sys software packages. These programs allow the user to create model geometries of the sub-surface, assign values for density and magnetic susceptibility, and compare the resulting calculated gravity and magnetic anomalies with observed data. Our model was created using a 2 1/4 D approach as outlined in the GMSYS user’s manual (Popowski et al., 2009). A 2 1/4 D model allows the user to specify how far each object extends into and out of the plane of the profile line, and also allows those objects to intersect the profile line at an angle other than 90°. The area beyond the edges of these defined shapes can only have one set of attributes. This area is designated in our models as “Country Rock”, and set to 1000 kg m⁻³ density and zero magnetic susceptibility. For simplicity and ease of comparison, all model objects inside the diatreme were specified to extend 0.7 km into and out of the plane of the model profile, perpendicular to the profile, for a total width of 1.4 km. We note that model results are only marginally sensitive to the width of these modeled objects, within reason constrained by the outcrop pattern of the crater and tuff ring. Stratigraphic and aquifer depth information shown on the model (Fig. 5) are derived from a well drilled roughly 20 km W of our study site (Hoffmann et al., 2006). The depths and thicknesses of units are approximations, as depth and stratigraphic characteristics may vary over relatively small distances.

Our magnetic calculations are based on apparent magnetization, a combination of induced and remnant magnetization described by:

\[ k_{\text{apparent}} = \frac{T}{H} \]  

where \( T \) is the magnitude of the total vector of magnetization, and \( H \) is the magnitude of the Earth’s magnetic field.

\[ \mathbf{T} = \mathbf{H} \cdot \mathbf{J}_T \]  

where \( \mathbf{H} \) is the magnetic susceptibility, and \( \mathbf{J}_T \) the magnitude of the vector of remanent magnetization. This estimate assumes that the vector of remanent magnetization is parallel to the current direction of the Earth’s field, \( \mathbf{H} \), which is a reasonable assumption for the normally magnetized Rattlesnake Crater anomalies.

Model 1:

The modeled diatreme has the same density as the surrounding country rock, with the exception of its innermost zone. The primary magnetic and gravity anomaly within the crater is modeled as a single body of relatively high magnetization and high density (2500 kg m⁻³ and 0.037 SI respectively), consistent with coherent basalt (Fig. 5, Coherent Body A). The thin vertical segment tapers out at a depth of approximately 1 km, although this depth is not especially well constrained. The vertical portion of Coherent Body A is topped by a thin horizontal body of similar density and magnetization which extends approximately 800 m along the profile line. This horizontal body either represents a lava flow deposited on the paleo-crater floor and buried by subsequent deposits, or a shallow sill within the diatreme. Coherent Body B is given the same density and apparent susceptibility, and also assumed to be a basaltic intrusion in this model. The diatreme is divided into zones of inwardly increasing apparent magnetic susceptibilities (0.013, 0.025, and 0.063 SI) and decreasing densities (1900 kg m⁻³ and 1800 kg m⁻³) similar to the approach of Mofina et al. (2009) (Table 1). The tuff ring surrounding the crater was modeled...
with a density of 1700 kg m$^{-3}$ and an apparent susceptibility of 0.037 SI. The top layer of fill in the crater was modeled as 1850 kg m$^{-3}$ with zero magnetic susceptibility.

Model 2 indicates a dip angle of 29°-43° for the inwardly-dipping diatreme walls. Along the E-W profile line, the diameter of the top of the diatreme is approximately 1.1 km, roughly the same width as the distance across the crater floor along the profile. The diatreme is not modeled below a depth of 1500 m, as the model is not sensitive to reasonable changes in density and susceptibility below that depth. If we assume an inverted cone-shaped diatreme, with inwardly-dipping walls of 80°, the maximum depth of the modeled base of the diatreme is about 3 km in Model 1. This depth is consistent with Valentine's depth estimate based on the seismic content of the tuff ring (Valentine, 2012). Using this depth and the inverted cone geometry, it yields a maximum diatreme volume of approximately 1 km$^3$. If instead that same cone is truncated at 1500 m, the maximum depth to which we modeled the diatreme, the diatreme volume is approximately 0.9 km$^3$. Based on these calculations, the volume of the diatreme beneath Rattlesnake Crater is approximately 0.9-1 km$^3$.

Model 2:

The diatreme in Model 2 extends to a depth of ~800 m, and maintains the dip angle on the outer walls of the diatreme of about 80°. As in Model 1, the primary magnetic and gravity anomaly within the crater (Fig. 5, Coherent Body A) is modeled as a single body of relatively high magnetization and high density; although the density is lowered from 2500 to 2400 kg m$^{-3}$, and the vertical portion of the body tapers out at a depth of 0.5 km. The horizontal component remains nearly identical in its geometry to Model 1. Coherent Body B is significantly different in its geometry, as well as having a lower modeled density of 2300 kg m$^{-3}$ and a much lower apparent susceptibility of 0.001 SI. While the susceptibility and density values assigned to this body in Model 2 are much lower than they were in Model 1, they are still significantly higher values than the surrounding diatremes. The higher magnetization and density indicates that Body B is likely some sort of coherent material, i.e., that is of uniform density and magnetic properties, although not of the same density or apparent magnetic susceptibility as Body A. Body B may represent a deposit of rhyolite or a mixture of rhyolite and dacite (e.g., Lefebvre et al., 2012), which would have a lower density and lower susceptibility than a lava flow or sill, but still significantly higher values than the surrounding diatremes.
the ~100 m of the profile beyond the rim. If these outward-dipping beds are part of a larger waveform, the wavelength must be ~250 m.

Beneath the crest of the tuff ring, reflectors to a depth of ~12 m form a very gentle trough filled with progressively slightly flatter layers (Fig. 6, Feature 2). One possible explanation is that gravity-driven faulting within the tuff ring, beneath the site of the current rim, created accommodation space. The trough progressively shallowed and flattened as successive deposits in-filled. Fall deposits from later eruptions may contribute to the trough fill. Alternatively, this feature may be part of a longer-wavelength depositional bedform. Brand and Clarke (2009) correlate wavelengths of surge deposit bedforms as a function of distance from the vent for 7 sites. Of these, the Rattlesnake western rim feature (~100 m wavelength; ~600 m from vent) fits most closely with a series of depositional packages documented at the phreotectomorphic Table Rock Complex in Oregon (Brand and Clarke, 2012, Fig. 2e). At the Table Rock Complex, the long wavelengths are interpreted as the product of super-critical flow conditions (Brand and Clarke, 2009) in which inflated base surge deposits can scour underlying material.

On the inside slope of the tuff ring, a trough of surficial sediments up to 5 m thick covers features that strongly diffract the GPR signal (Fig. 6, Feature 3). The U-shaped features on the radargram near Feature 3 are an artifact of imperfect collapse of diffractors in the 2D migration of the data. We interpret these diffractors as the shallow terminus of beds that have been truncated by erosion or slope failure on the inner face of the tuff ring. Similar truncation surfaces have been observed in outcrop at other tuff ring locations (Sohn and Park, 2005; Brand and Clarke, 2009, 2012). Another trough filled with surficial sediments lower on the slope (Fig. 6, Feature 4) is most likely the result of grain avalanching. Towards the bottom of the tuff ring (Fig. 6, Feature 5), a set of buried reflective horizons overlap each other and dip towards the crater. These could represent on-lap deposits from successive surges within the crater.

There are horizontal reflectors to about 8 m deep beneath the crater floor (Fig. 6, Feature 6). These are the result of post-eruptive fill layers and/or soil horizons. Deeper reflectors within the crater cannot be interpreted reliably due to high attenuation within the crater. We suspect this higher degree of attenuation is related to soil development on the crater floor.

GPR Profile 2 (Fig. 7) is a 250 MHz survey line collected on the eastern side of the tuff ring. The profile starts at the crest and continues east, away from the crater, and down the outer slope of the tuff ring. The units beneath the crest of the tuff ring (Fig. 7, Feature 1) are not strongly horizontal, as they are on GPR Profile 1, but dip steeply (approximately 50°) away from the crater. This difference highlights the variable nature of the depositional and/or post-depositional processes affecting the tuff ring.

Downslope from the crest, the reflecting units exhibit symmetrical wave-like features (Fig. 7, Feature 2) with wavelengths of ~100 m, and amplitudes of ~5–8 m. The depth of penetration for this profile is ~10 meters, so the total thickness of these wave packages is unknown. These features are much longer than most sandwaves reported in the literature (Sheridan and Updike, 1975; Cole, 1991; Cagnoli and UlyUC, 2001; Douillet et al., 2013, others). However, as discussed above for the dimension of the trough on the western rim profile, such wavelengths have been reported at the Table Rock Complex in Oregon (Brand and Clarke, 2008, 2012). Although outcrops at Rattlesnake Crater are sparse, anti-dune structures are present in the upper units of the tuff ring (Valentine, 2012). The presence of anti-dunes, typically interpreted as the result of highly energetic deposition, lends further strength to the hypothesis that the reflectors seen in the GPR data may be similar in origin to those at Table Rock.
Comparison of GPR data to exposures of dune and sandwave structures documented at other tuff rings could be a valuable tool for studying the eruption dynamics of late-stage phreatomagmatic activity at locations with no cross-sectional tuff ring exposures.

Discussion

Rattlesnake Crater is elongate in a NW-SE direction, the primary orientation of fractures in the area. Nearly all other phreatomagmatic eruption sites in the eastern part of the SPVF also appear to be oriented in this direction. Locally, there are also significant numbers of non-phreatomagmatic volcanic features that have multiple vents or that are elongate in this orientation, such as The Spread, near Meridian Crater (Hsu, 2014). The highest-amplitude magnetic anomalies within Rattlesnake Crater and the vents on Rattlesnake Hill are co-linear and NW-SE trending (Figs. 3 and 4). Based on these observations, we suggest that underlying structural control was responsible for creating aligned features associated with Rattlesnake Crater, and may have aided the flow of groundwater to drive the phreatomagmatic eruption. The relatively impermeable country rock is highly fractured in the eastern part of the SPVF (Gettings and Bultman, 2005), and these fractures hold significant quantities of water (Mongeoney and Hazzahberger, 1992; Morgan et al., 2004). It seems logical that phreatomagmatic activity in the SPVF might be triggered by the interaction of magma with these water-filled fractures (e.g., Lorenz, 2003).

Outcrop studies (Valentine and White, 2012; Lefebvre et al., 2013; Delpeut et al., 2014) indicate significant local variations in ash/tephra ratios, grain size, and bedding characteristics; and the occurrence of steeply-dipping contacts are commonplace within diatremes. Diatremes exhibiting zones with highly variable internal properties have also been documented by cores (Brown et al., 2009); physical blast experiments (Graettinger et al., 2014) and geophysical modeling (Blakie et al., 2014). We interpret the zones of variable density and magnetic properties required to model Rattlesnake Crater gravity and magnetic data in terms of these observations. Modeling of our geophysical data (Fig. 5) suggests that the outermost areas of the diatreme carry the lowest magnetization, yet still have significant apparent magnetic susceptibility contrast with the surrounding, undisturbed country rock. This result is consistent with diatreme deposits containing a relatively low proportion of ash and related juvenile material, and possibly containing blocks, or megablobs of country rock and reworked material emplaced at low temperatures (Delpeut et al., 2014). Studies of exposed diatremes show zones along the outer portion can be very rich in wallrock material (Lefebvre et al., 2013). Diatreme Zone 1 carries higher magnetization than zones 2 in both Models 1 and 2 (Fig. 5). This higher magnetization is likely due to a higher proportion of basaltic fragments in this part of the diatreme. The zones of varying susceptibility within the central part of the diatreme (i.e. Zone 1 and 2) may be a result of a migrating vent within the crater (e.g., Kurzanski and Falbo, 2013), or represent a change in eruption dynamics over time.

Diatreme Zone 2 has a density that is consistent with recycled pyroclastic material, but it carries much higher magnetization than expected for such a deposit. The apparent magnetic susceptibility is unlikely to be produced by randomly oriented basalt fragments emplaced at low temperatures, as might be the case in Diatreme Zone 3, because these fragments would have randomly oriented vectors of remanent magnetization. Instead, the high magnetization suggests Diatreme Zone 2 is uniformly magnetized. Its low density and high magnetization are consistent with hot emplacement of non-bedded pyroclastic zones within the diatreme, such as those interpreted to be formed by late-stage intra-diatreme fragmentation (Delpeut et al., 2014). The asymmetry of density and susceptibility within the diatreme is also consistent with random explosion deposits and/or multiple shallow explosions suggested at other maar-diatremes (Valentine and White, 2012; Blakie et al., 2014). (Brown et al., 2009; Blakie et al., 2014; Graettinger et al., 2014).

GPR data reveal possible on-lap features on the lower walls of the crater (Fig. 6, Feature 5), suggesting multiple episodes of phreatomagmatic activity within the crater. GPR data also suggest that the irregular shape of the tuff ring may in part result from faulting on the western side of the ring. We cannot say if the hypothesized faults developed during the eruptive phase of the maar or later, but the uppermost units on Profile 1 (Fig. 6, Feature 2) indicate failure occurred before eruptive activity ceased. The geometry and wavelengths of the pyroclastic units revealed in the GPR data (Figs. 6 and 7) suggest that at least some of the eruptive activity at Rattlesnake Crater was highly energetic. Pyroclastic material deposited under high-energy conditions in thick deposits could create the proper conditions to maintain elevated temperature long enough to acquire relatively high TIR, which accounts for the positive magnetic signature of the tuff ring (Figs. 3 & 4, Feature 8). We suggest that this high emplacement temperature is consistent with intra-diatreme fragmentation (diatreme Zone 3), following emplacement of diatreme Zones 1 and 2.

The highest amplitude gravity and magnetic anomalies in the crater are related to the dense magnetized body in the center of the crater (Fig. 5, Coherent Body A), which we interpret as a dikes intrusion, with a horizontal component that is either a lava flow or a shallow sill located at a depth of 30–40 m beneath the present surface. There are several examples in the exposed diatremes of the nearby Hopi Buttes volcanic field of significant basaltic intrusions emplaced after phreatomagmatic activity ceased (e.g., White, 1991), and late-stage lava ponding is a feature that has been observed at other maar (e.g., Risto et al., 2008).

Body B on the right side the diatreme (Fig. 5) could be an intrusion emplaced in a similar manner to Body A or it could be comprised of spatter internally deposited within a diatreme, as described by (Lefebvre et al., 2012) at Castle Butte South. In that case, spatter deposits were interpreted as the result of pulsating, weak, hot fragmentation (Lefebvre et al., 2012). While most of our geophysical data suggest an en masse explosive history, spatter deposits could have developed during the transition from phreatomagmatic activity to cone building.

A Brunhes-age magnetic orientation and the presence of ash from Sunset crater establishes an age of 900–780,000 Y.P. for Rattlesnake Crater. The presence of well-developed scouring horizons in the GPR data suggest Rattlesnake Crater erupted a significant period of time before the Sunset Crater eruption 900 years ago. The relative timing of the formation of the crater and the scoria cone is inconclusive. Deposits from Rattlesnake Hill do overlap the crater and tuff ring in some places. But there is also magnetic evidence that suggests a lava flow from Rattlesnake Hill is covered by material from the tuff ring (Figs. 3 and 4, Feature C). It is not clear if the lava was buried through primary deposition or through the gravitational deformation of the tuff ring through remobilization of pyroclastic sediments over time. Additionally, the presence of a possible unconformity within the tuff outcrop containing basaltic bombs (Valentine, 2012) may also indicate the crater and cone were active concurrently. In any case, it is clear from the geophysical data and their interpretation that Rattlesnake Crater did not form from a simple explosion, but instead was shaped by a series of events including energetic surges, vent migration, dike emplacement, and lava flows.

Conclusions

Gravity and magnetic data provide a basis for modeling the subsurface geometry of the diatreme associated with Rattlesnake Crater. While forward models can have significant uncertainty, the comparison of two models, each developed from both magnetic and gravity data, helps to illustrate the overall concepts required to achieve a good fit to our geophysical data. The gravity and magnetic anomalies indicate the diatreme is not uniform, but instead comprises zones of variable density and magnetization. These zones indicate variable ratios of country rock and juvenile material in the diatreme, shifting vent location through time, and the presence of dense magnetized bodies within the diatreme.
The presence of low density, highly magnetized zones within the diametre is consistent with massive, unbedded pyroclastic deposits produced by intra-diametre fragmentation. Approximately 5% of the diametre, by volume, consists of dense, highly magnetized rock that is interpreted as a late-stage basalt intrusion and/or possible lava flow, on the crater floor or a shallow sill within the upper deposits of the diametre.

The elongate NW-SE orientation of the crater is mirrored by magnetic anomalies on the crater floor, which are also co-linear with mapped basaltic vents on Rattlesnake Hill. These observations are consistent with the presence of a large, gently dipping, basaltic sheet, and the possibility that the pyroclastic manifestations were driven by the interaction of a magma dike with groundwater contained in fractures of the same orientation. While not commonly observed at pyroclastic volcanoes, GPS data reveal the presence of long-wavelength features, complimented by anti-dunes in outcrop, to suggest Rattlesnake Crater experienced an episode of unusually energetic eruptive activity at some point in its formation.

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