"Living With Volcanoes": Cross-Curricular Teaching in the High School Classroom

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ABSTRACT

A new, interdisciplinary high school geoarchaeology curriculum unit, titled "Living with Volcanoes," was created and tested in two pilot lessons with 30 high school students total studying geography and classical civilization in northern England. Students were highly engaged during the curriculum unit and showed positive learning gains and favorable shifts in perceptions as measured immediately before and after its implementation. Geoarchaeology combines disciplinary knowledge from geoscience and archaeology to construct novel approaches to past human inhabitation and environmental interaction. The curriculum unit was designed to introduce this field to high school students, following guidelines from interdisciplinary studies, and it was modified iteratively, based on interviews with four high school teachers of relevant classes. It combines short lectures and group work in a 90 min, interactive format to address a variety of questions surrounding the eruption of Mt. Vesuvius and its impact on the town of Pompeii and other nearby areas. Pilot survey and observational data, combined with feedback from students and teachers, were used to modify the curriculum unit. Restructured case study questions now provide better scaffolding for students, and teachers are provided with an answer key to better support facilitation. "Living with Volcanoes" has the potential to be utilized in cross-disciplinary recruitment for both geoscience and archaeology, at the high school and introductory postsecondary level. This broader, interdisciplinary approach to curriculum development may be applied to other fields of geoscience that transcend common disciplinary boundaries. © *2015 National Association of Geoscience Teachers*. [DOI: 10.5408/14-048.1]

Key words: high school, K–12, A-level, interdisciplinary, group work, volcanic hazards, geoarchaeology, geography, classical civilization, space and Earth Science

INTRODUCTION

Geoarchaeology utilizes the overlap between geoscience and archaeology in approaches to questions of past occupation, settlement, and subsistence strategies, addressing the interconnectedness of humans with their environments. Most practitioners of geoarchaeology consider it to be a driver of conceptual questions and an integrated component of archaeological studies, rather than simply an application of Earth Science techniques (e.g., Butzer, 1982; Canti, 2001). Geoarchaeology is a unique and exciting field, ripe with potential for novel, interdisciplinary teaching and learning opportunities. This potential is largely unexploited at the high school level, perhaps due to the paucity of geology and archaeology being taught (e.g., Fleming, 2000; Thomas et al., 2013). Many students leave high school unfamiliar with the potential study and career options that geology and archaeology offer.

Here, we address the gap in high school geoarchaeology pedagogy by developing the 90 min "Living with Volcanoes" curriculum unit to introduce high school students and teachers to the lesser known subject of geoarchaeology and its disciplinary constituents, geoscience and archaeology. Within this curriculum unit, students are taught independently about archaeology and volcanology, with examples of geoarchaeological connections, before being tasked with applying and synthesizing their knowledge cohesively. This latter portion of the curriculum unit centers on a case study spatially and temporally surrounding the eruption of Mt. Vesuvius in 79 CE, and it is completed collaboratively in groups. "Living with Volcanoes" was designed to not only address content goals spanning the range of disciplinary knowledge involved, but also to address perceptions of geoarchaeology and interdisciplinarity in general.

After situating this work within its relevant research context, this paper describes the study population and setting within which the curriculum unit was developed and tested. The approach to curriculum development and implementation, measures of effectiveness, and limitations are then detailed. Finally, recommendations for future implementation, including additional work, are described.

CONTEXT

Interdisciplinary Theory and Pedagogy

Geoscience has long been connected to archaeology. Many of the earliest archaeological investigations were conducted by geologists (Butzer, 1982; Rapp and Hill, 1998). The need to comprehend a cohesive site history drives geoarchaeology and other interdisciplinary approaches to archaeology, where concepts are effectively integrated to solve a problem (Butzer, 1982; Canti, 2001; Fouache, 2007; Fouache et al., 2010). Interdisciplinary thought advances problems in novel ways (Repko, 2008), perhaps in ways that might not have been possible with a single disciplinary perspective (Newell, 2007). It reflects the real world more

Received 30 July 2014; revised 16 March 2015 and 8 June 2015; accepted 1 September 2015; published online 14 December 2015.
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accurately (Thomas, 1975; Newell, 2007), as an interconnected system rather than agents in isolation.

Practical components of high school curricula (i.e., labs and tutorials) have been suggested as a useful venue for integrative interdisciplinary content (Singer et al., 2005). Inquiry-based learning, team/group work, and case studies (i.e., active learning) are common pedagogical strategies (Klein, 2005, 2006). When students actively engage with the content in their classroom through their instructors and, primarily, through their peers, they attend more classes, learn more, and strengthen critical thinking and reasoning skills (e.g., Hake, 1998; McConnell et al., 2005; Deslauriers et al., 2011). As students engage using collaborative interdisciplinary approaches, they show improved motivation for novel problems, strengthen their own disciplinary skill sets, and learn the practice of cross-disciplinary communication (Vale et al., 2012).

Interdisciplinarity in Geoscience Teaching and Learning

Geoarchaeology

As geoscience and archaeology are relatively uncommon at the high school level, there is plenty of impetus to integrate them with more widely taught subjects (e.g., Fleming, 2000; Lee and Fortner, 2005; Henson, 2008; Thomas et al., 2013). Unfortunately, this is difficult to do with geoarchaeology when the majority of geoarchaeological education is centered on the advanced undergraduate or graduate level. Donahue and Adovasio (1985) reported on one of the first geoarchaeology courses, focused on the physical environment. Although the authors described the course as interdisciplinary and cross-listed it between anthropology and geology, they did not discuss any broader approaches to interdisciplinary education. Nicolaysen and Ritterbush (2005) reported on their project-based undergraduate course in archaeological geology aimed at developing higher-order thinking skills; however, they focused on the specifics of one materials-based project. Barrett et al. (2004) developed an interdisciplinary course with an archaeogeophysical survey hosted in geology, archaeology, and geography programs. Particular emphasis was placed on active learning, discussion, collaboration, and research. Barrett et al. (2004) believe that their interdisciplinary approach is "better pedagogy and better science" (p. 236). Battles and Hudak (2005) detailed module concepts and materials on cave art in an interdisciplinary, problem-based art and geology honors seminar, though they did not describe any general aspects or approaches to interdisciplinary design.

Other Interdisciplinary Geoscience Fields

Curricula have been developed for a range of other interdisciplinary topics involving geoscience, including geomicrobiology (Hernández-Machado and Casillas-Martínez, 2009), watershed science (Pearce et al., 2010), the physical world (Earth Science, astronomy, and physics; Plotnick et al., 2009), Earth and space science (Cervato et al., 2013), climate change (Balgopal et al., 2014), and environmental education (Tal, 2005). Many of these authors identify their teaching or topic as interdisciplinary (and some teach in interdisciplinary teams) and describe the need to consider problems or questions from a holistic, or systems, viewpoint. Several refer to the logistical difficulties of creating interdisciplinary learning experiences, particularly in university systems (e.g., Barrett et al., 2004; Plotnick et al., 2009; Pearce et al., 2010). However, it is ultimately seen as beneficial to engage in these sorts of teaching and learning opportunities, as all of these authors took the time and effort to develop novel, interdisciplinary modules and courses. Despite alluding to these benefits, it is not clear whether or not recommended interdisciplinary theory and pedagogy were used in developing and structuring the relevant curricula.

STUDY POPULATION AND SETTING

The "Living with Volcanoes" activity was developed and implemented in England in June 2013, with consideration of the national school system and curricula. Though the study population and setting themselves are not particularly unique, it is important to understand how schooling is structured in the country and what components of the national curricula might be relevant. These components are relevant to U.S. and New Zealand national standards in related subjects, demonstrating the applicability of the curriculum unit to many contexts (Table I). In addition, the student and teacher populations involved in the formation of the activity and the instructional conditions for its pilot implementation are described below, in order to assist in understanding its transferability.

Educational Structure

The students that participated in the curriculum unit were studying university entrance A-levels (ages 16–17) in England, equivalent to the 11th and 12th grades of high school in the United States and Levels 2 and 3 of the National Certificates of Educational Achievement (NCEA) in New Zealand. At A-level, students typically choose four subjects to study during the first stage (AS). They then drop one of these for A2, the final stage of A-levels, completing qualifications in three subjects. Therefore, students at A-level develop in-depth knowledge in a smaller number of fields, in contrast to U.S. and New Zealand high school education, where students develop broader knowledge in a larger number of fields. As the curriculum unit was developed to be applicable to both science-focused students interested in the humanities and vice versa, it is expected that it will also be suitable for educational systems broader than that of the United Kingdom. Therefore, examples of curricular standards in two other countries (U.S. and New Zealand) are included for reference.

Related United Kingdom, United States, and New Zealand National Curriculum Standards

Geography (offered at all schools) and classical civilization (offered at the majority of schools) are the most widely taught A-level subjects that are closely related to geoarchaeology. Geology is not widely offered at this level, and no geology classes were a part of this pilot study. However, the geography curriculum is well representative of the modern-day intersections of cultural and environmental processes, whereas geoarchaeology can loosely be conceptualized as the past interactions between these concepts. Moreover, studies in classical civilization involve the physical and social contexts of the art, architecture, and literature, making geoarchaeology highly relevant. Related high school subjects in the United States include: geography and world

TABLE I: United Kingdom, United States, and New Zealand National Educational Standards that may be addressed using the "Living with Volcanoes" curriculum unit. Note that the A-level archaeology curriculum is not considered here, because it has no analogues in the United States or New Zealand (NZ) standards.

Subject	UK Standards (A-levels, AS and A2)[1,2,3]	U.S. Standards (High School, 9th–12th grades)[4,5,6]	NZ Standards (NCEA, Levels 2 and 3)[7]
Geography	Rivers, floods, and management—the long profile (processes of sedimentation)	The physical processes that shape the patterns of Earth's surface; how to apply geography to interpret the past	Demonstrate geographic understanding of a large natural environment
	Plate tectonics and associated hazards—volcanicity (major volcanic landforms)	The physical processes that shape the patterns of Earth's surface; how physical systems affect human systems; how to apply geography to interpret the past	Demonstrate geographic understanding of a large natural environment
	Development—economic, social, etc., changes	The characteristics, distribution, and migration of human populations on Earth's surface; the processes, patterns, and functions of human settlement; how to apply geography to interpret the past	Demonstrate geographic understanding of differences in development; demonstrate understanding of how a cultural process shapes geographic environment(s)
	Food supply issues—geopolitics of food	The changes that occur in the meaning, use, distribution, and importance of resources; how to apply geography to interpret the past	Demonstrate understanding of how a cultural process shapes geographic environment(s)
Classical civilisation/ world history/ classical studies	Roman architecture and town planning—town/building design, building materials, decoration, implicit societal values	Evaluate the major legal, artistic, architectural, technological, and literary achievements of the Romans and the influence of Hellenistic cultural traditions on Roman Europe	Examine/analyze ideas and values of the classical world; demonstrate understanding of a significant event in the classical world; examine sociopolitical life in the classical world
Geology/ Earth and space sciences/ Earth and space science	Understand the characteristics and distribution of volcanic products	Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes (middle school)	N/A[8]
	Understand the characteristics of volcanoes	Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features	N/A[8]
	Appreciate the social and economic effects of volcanic activity	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity	Investigate a socioscientific issue in an Earth and space science context
	Understand the influence of gravity, wind, ice, the sea, and rivers in the formation of sediment (describe and analyze characteristics of grain shape and size)	Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes	N/A[8]

[1]AQA (2011).
[2]AQA (2009a).
[3]OCR (2013).
[4]National Geographic (2012).
[5]NGSS Lead States (2013).
[6]UCLA (2012).
[7]NZQA (2015).
[8]The standard "Investigate geological processes in a New Zealand locality" addresses the process aspect of the compared UK standard; however, the spatially specific nature of the New Zealand standard means that they are not, strictly speaking, compatible.

history. Relevant New Zealand NCEA subjects include: geography and classical studies. Specific educational standards that may be addressed using the curriculum are described in Table I.

Teacher Population

Four female teachers from three schools were interviewed during curriculum development, three from classical civilization and one from geography. One of the schools was public, one was Catholic (or parochial), and one was from an independent service provider (private). All of the schools achieved a 99% pass rate for the most recent A-level examinations, and the public and Catholic (or parochial) schools were rated as "outstanding" in their most recent inspection reports (Ofsted, 2008, 2013). A teacher from each of these two schools, one from each discipline, elected to participate in the pilot implementation of the curriculum.

Student Population

A total of 30 students (majority 17 years of age) participated in the pilot implementation of the "Living with Volcanoes" curriculum unit. Just over half of these were from geography, and the others were from classical civilization classes. Few students were studying both geography and classical civilization at A-level, but some had studied the other subject at lower levels of schooling.

Prior Knowledge

Given the curriculum standards for A-levels (AQA, 2011), it was expected that geography students would be familiar with maps, photographs, graphs and statistics, developing skills of investigation, and interpretation. Prior to A-levels, relevant topics include: "The Restless Earth (hazards)," "Rocks, Resources, and Scenery," and "Population Development" (AQA, 2012).

For classical civilization students, literacy and critical-thinking skills are particularly important (AQA, 2009a). Prior to A-levels, relevant topics include: "History of Roman Britain," "Archaeology of Roman Britain," and "Pompeii and Herculaneum" (AQA, 2009b). Students also discuss social life and civilization as it relates to specific art and literature that are studied.

Although some geoarchaeologically relevant topics were present in the pre–A-level curriculum for geography and classical civilization, no prior content knowledge was expected of the students. This is due to two reasons: (1) With interdisciplinary learning as a key aim of the curriculum unit, it was important that it be easily accessible to a variety of audiences (both science and the humanities), with no modifications necessary or added knowledge expected, and (2) the menu-like school curriculum structure means that teachers can pick and choose topics from each section, and it could not be guaranteed that students had studied specific topics.

Instructional Setting

The pilot curriculum unit was implemented in two different scenarios over a 2 h period. The geography students participated in the activity in regular class time, with two classes combined into one. This meant that it was double the length of a normal class period, with double the students. The classical civilization students participated in the activity outside of class time, offered as an enrichment activity for those who were interested in learning more about archaeology and/or geoarchaeology.

CURRICULUM UNIT DESIGN AND IMPLEMENTATION

Curriculum Unit Structure—Interdisciplinary Approach

Through the earlier portions of the activity, disciplinary knowledge and perspectives of archaeology and volcanology are taught in interactive lecture sections 1 and 2 (Fig. 1; supplemental file 1, which is available online at http://dx.doi.org/10.5408/14-048s1). Each of these lecture sections is immediately followed by a set of case study questions (supplemental files 2 and 3, which are available online at http://dx.doi.org/10.5408/14-048s2 and http://dx.doi.org/10.5408/14-048s3), where students have the opportunity to analyze archaeological and volcanological data (e.g., historical accounts, images of artifacts, and sediment samples) by applying disciplinary knowledge gained in the lecture sections. These data are not introduced until the case sections. The case study questions finish with a synthesis that requires students to connect the two disciplines completely, followed by a summary lecture to clarify these connections. This design reflects the recommended structure for interdisciplinary education: foundational knowledge, separate models or perspectives (discipline specific), analysis (actively using the models or perspectives), and synthesis (e.g., Newell and Green, 1982; Klein, 2005; Repko, 2008).

Curriculum Unit Content—Volcanic Hazards

Natural hazards were selected as the content focus, for several reasons. (1) They are crucial to understanding the processes by which archaeological sites form and are preserved, a fundamental geoarchaeological concept. Moreover, re-inhabitation of hazardous environments is an important, related concept. (2) Natural hazards easily bridge geology and archaeology through environmental processes and cultural impacts. (3) They are relevant to students in the real world through a range of contexts, e.g., management, development, and tourism. Volcanic hazards, in particular, were selected because they have connections to national curricula, were expected to be engaging to most students, and were aligned with researcher and expert interest and experience.

Iterative Curriculum Unit Modifications—Pre-Interviews with Teachers

The pre-interviews covered four major themes: (1) the teaching context and goals for instruction, (2) students' prior knowledge, skills, and engagement, (3) teachers' perceptions of geoarchaeology and interdisciplinarity, and (4) preliminary feedback about the curriculum unit. The interviews were semistructured; i.e., the questions were preplanned, but their wording, order, and follow-ups were flexible (Cohen et al., 2007). Interviewees were told to treat it as an informal conversation. Following each teacher interview, the curriculum unit was revised, resulting in consistent learning objectives and a final design.

None of the teachers was previously familiar with geoarchaeology; however, all were interested in geology and/or archaeology and learning more about them. Teachers noted that active learning and group work were important

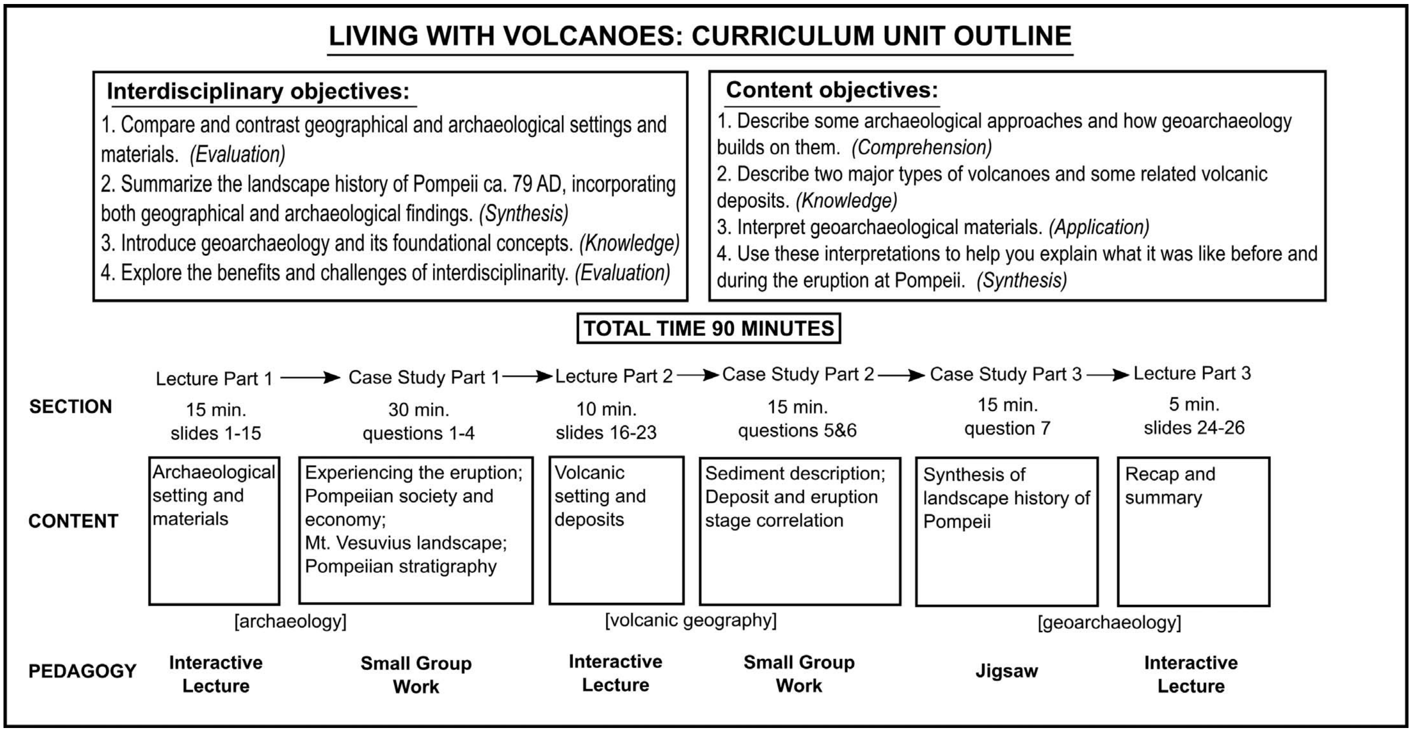

FIGURE 1: Outline of the "Living with Volcanoes" curriculum unit objectives (with associated level of Bloom's Taxonomy; Bloom et al., 1956), structure, and content. The activity intersperses short, interactive lectures (foundational knowledge) focusing on introducing archaeology and volcanic geography with case study questions that require students to work in groups and apply this new knowledge to real data (application and analysis). Finally, the groups combine the disciplines by compiling the landscape history of Pompeii using a jigsaw format (synthesis), before the teachers facilitate a summary of this. The curriculum unit contains two times as much practical work as lecture and no more than 15 min of continuous lecture.

pedagogical tools for building and sustaining student engagement, and that they were well suited to the interdisciplinary model for curriculum structure. They also felt that volcanic geoarchaeology (and particularly, Pompeii) matched with both subject matter that might interest their students and that could be easily matched with A-level curricula, which was ultimately the most important determining factor in what they chose to teach in their classes. All of these points were consistent with the initial activity design, and thus no major modifications were made to the curriculum unit structure or content.

All teachers described broad, holistic goals for their own classes, with a clear emphasis on critical thinking and connections to people and society. There were some perceived differences in the classical civilization and geography student populations, however. Classical civilization teachers indicated that many of their students were unfamiliar with methods of data analysis and presentation and tended to have less developed observational skills. One of these teachers was also concerned about the potential for the curriculum unit to include an excessive amount of scientific data. It was important to ensure that classical civilization students in particular had sufficient guidance throughout the activity, by providing examples and/or frameworks where appropriate.

All of the interviewees thought of their field, classical civilization or geography, as interdisciplinary. However, they were able to provide only limited examples of interdisciplinary teaching in their classrooms, past or present. The teachers attributed their difficulty with this approach to its time-intensive organization and often unfamiliar content. In spite of this, interdisciplinary teaching was thought to be beneficial for the teachers, by building appeal of the subject and thereby enhancing student enrollment. It was also thought to be beneficial for the students, by helping them experience the content in action, see its relevance, and become more creative problem solvers. With a prebuilt curriculum unit and accompanying resources, we were hopeful that the logistical hurdles commonly associated with interdisciplinary teaching could be surmounted in favor of these benefits.

Strategy for Curriculum Unit Implementation

Two teachers were able to participate in the pilot implementation of the curriculum unit. Though the other two interviewees found the curriculum unit of interest and were enthusiastic about teaching it in their classrooms, they were unable to do so given time constraints. Two weeks of preparation time were provided, along with the final curriculum unit and a teaching guide (supplemental file 4, which is available online at http://dx.doi.org/10.5408/14-048s4), describing the rationale behind its design and recommendations for its implementation. Teachers were encouraged to pose questions and interact with the students during the lecture sections and facilitate during the case study sections, but the nature and extent of this were adaptable to their own personal teaching style. It was recommended that students work in groups of three to four during the case study, as previous work suggests larger group sizes may be detrimental (Dohaney et al., 2012).

Materials Needed for Curriculum Unit Implementation

All materials needed to successfully deliver the curriculum unit are listed and described in the teaching guide, the majority of which are PowerPoint slides and paper handouts (case study questions, reference figures, and key terms; see supplemental file 5, which can be found online at http://dx.doi.org/10.5408/14-048s5), and material containing open-access audiovisuals. These are available as supplemental materials to this article, as well as online (http://serc.carleton.edu/NAGTWorkshops/environmental/activities/86215.html). A few samples and maps are needed and can easily be replicated and/or altered where necessary.

EVIDENCE OF CURRICULAR EFFECTIVENESS

Various data were collected to determine the impact of the ''Living with Volcanoes'' curriculum unit on the students and teachers involved in its implementation. These data are described next and include: observations of teachers and students during the curriculum unit, student responses to case study questions, student pre- and postinstruction questionnaire responses (concept, perception, and feedback), and postinstruction interviews with teachers.

Observations of Teachers and Students During the Activity

A simple observation protocol was developed based upon a sampling of existing protocols and modifications in the science education literature (Hora and Ferrare, 2009; Kennedy et al., 2013; Smith et al., 2013). Two main aspects of the classroom were characterized through the observations: what the teacher was doing (techniques and timing), and how many of the students were engaged with the material (using behavioral cues, as suggested by Lane and Harris, 2015). Every 3 min, the researcher (coauthor A.J.) wrote down each of these parameters on a standard observation protocol sheet (Appendix A) and, for the majority of the time, was a nonparticipant observer. Ten students were randomly selected to observe throughout the lecture portions of the curriculum unit, as previous work has shown that a subsample of this size is indicative of overall class engagement (Kennedy et al., 2013). During the small group-based case study questions, an engagement rating was given out of the total number of groups (four, in both cases). If an individual or group was not consistently engaged or disengaged, a half-point rating was given.

Teacher Delivery of the Activity Material

Both of the teachers that participated in the pilot curriculum unit implementation succeeded at delivering the material clearly, despite their initial worries about not being knowledgeable enough about geoarchaeology. During the teaching slides, both teachers integrated lecture style instruction with provided examples. No questioning sequences were provided on the slides or in the teacher preparation material, yet both teachers were able to seamlessly pose improvised questions relevant to their own discipline. There were minor stylistic differences in the delivery of the material.

Student Response to the Activity Material

Students of both classes were highly engaged throughout the curriculum unit, though this was more variable during the case study questions. In both the individual (lecture) and group (case study) sections, Class B (classical civilization) had a higher average engagement than Class A (geography), though neither was significantly different (lecture, individual: B = 8.67 vs. A = 8.25, $p = 0.29$; case study, group: B = 3.08 vs. A = 2.81, $p = 0.37$). Generally, engagement was lower in the later lecture sections and at the beginning of case study question sections. Students appeared to be especially engaged with the hand samples during the sediment analysis question, though they struggled with identifying differences in grain size distribution and required additional guidance.

Evidence of Student Work

One question sheet for the case study sections was given to each group, and students were asked to make supporting notes to eventually help them with the final, long-form synthesis question. Unfortunately, the sheets were sparsely completed, and response rate declined through the activity, with the exception of the stratigraphic and sample description tables. Neither class fully completed the final essay question, as one teacher accidentally skipped it, and the other ended the class early. The curriculum unit was modified to mitigate this issue, and these changes are detailed in the ''Future Uses of Curriculum Unit'' section of this manuscript. Some of the students that did begin to fill out the essay question showed complexity in their answers, as exemplified in the following:

> ''*Before* [the eruption]*: Pompeii would have been a rich farming town. We can tell this firstly from the murals that depict farmers tending to the land on and around the slopes of Vesuvius. We also know that land around Vesuvius would have been ideal to farm on due to its fertility from the* [volcanic] *ash. Arts would have been critical to daily life, we can see this from the large, grandly furnished temple and the abundance of*'' [ends here]. (Group 4, Class A)

Impact on Student Knowledge and Perceptions

A short (10 mins pre-instruction, 15 min postinstruction) questionnaire (Appendix B), based upon the learning objectives of the curriculum unit, was completed by the students before and after the unit was taught. Because there were no developed or validated geoarchaeology inventories in the literature, it was necessary to construct new ones. It was outside the scope of the study to entirely validate the questionnaire (e.g., Adams and Wieman, 2011), but the questionnaire was based loosely on existing validated concept (Libarkin and Anderson, 2005; Libarkin, 2008) and perception (Adams et al., 2006; Walker, 2006; Jolley et al., 2012) surveys. Additionally, an expert in geoarchaeology (coauthor G.A.) ensured the content validity (i.e., correct phrasing and questions covering appropriate content) of the questionnaire. A five-point Likert scale (Likert, 1932) was used for the perception questions, and the knowledge questions were open-ended. Demographic information was collected on the pre-instruction questionnaire, and four open-ended questions regarding curriculum unit feedback were asked on the postinstruction questionnaire.

Results from Pre- and Postinstruction Questionnaires

The curriculum unit improved students' understanding of basic volcanic geoarchaeology concepts, at least immediately after its implementation, with an average learning gain of 0.42 on the knowledge questionnaire, similar to interactive courses in other studies (e.g., Hake, 1998). There were no significant differences in learning gains between the class enrolled (geography or classical civilization) or additional classes taken (geography students that had taken at least one classical civilization class and vice versa).

Not only did students make gains in geoarchaeological knowledge, their perceptions of geoarchaeology and interdisciplinarity also shifted. Students averaged significantly favorable shifts (with respect to the curriculum unit objectives) in their perceptions of: the usefulness of connecting disciplines, imagining connections between archaeology and other disciplines, the strength of connecting archaeology with other disciplines, and feeling like they have a good idea about what it means to study geoarchaeology. More students also felt that geoarchaeology would be fun to study, but this shift was not significant. More students felt that it was ''time-consuming'' to connect disciplines; however, this shift was insignificant.

Curriculum Unit Feedback

Student Feedback on Postinstruction Questionnaire

Four open-ended questions aimed at directing student feedback were asked on the pre- and postinstruction questionnaire, asking for the most enjoyed, least enjoyed, most challenging, and easiest portions of the activity and why. The most enjoyed aspects of the activity were generally related to the case study questions [hand samples, range of resources available, cultural aspects included, group work; Fig. 2(a)], as well as the examples/multimedia included in the lecture. The least enjoyed aspects were the questionnaire and the tendency to feel lectured at. Some students did not enjoy the hand samples, generally attributing this to their difficulty level, e.g., ''Analysing the rocks, as I found it difficult'' (student, Class A). In contrast, some students seemed to find the hand samples to be the easiest aspect of the activity [Fig. 2(b)]. Others thought the easiest aspects were the cultural components and the lecture. There was a greater range of student responses regarding the most challenging aspects of the activity, though the case study questions were slightly more frequent.

Teacher Feedback During Postinstruction Interviews

Following the activity implementation, teachers participated in 15 min, scope-limited, semistructured postinstruction interviews. These were focused on the teachers' experience and feedback regarding the preparation process and the instruction of the activity.

Teachers were largely positive about their experience, with minor recommendations for future implementation of the activity. They perceived the activity to be highly engaging to their students, whom they both found to be slightly more talkative than usual. One teacher attributed this to the timing of the activity (shortly after the exam break at the end of the school year), while the other attributed it to the fact that they were engaging with the material:

> *''I was happy* [with] *how they engaged with it…the group work…I think some groups worked better than the others but they do in any class…it kept them interested. And the ones that were really keen, I found it, it stretched them as well. You know, they're finding, they're doing stuff out of real life....''* (Teacher B)

The teachers did not find the material difficult to teach, but they would have preferred an answer key for the case study questions so that they could feel more confident in facilitating the group work, especially the grain size analysis question. One suggested that built-in questioning slides might help focus the interactive lecture portions. The teachers identified the biggest strength of the curriculum unit to be its practical and hands-on content. Both teachers said that they would use the activity for enrichment purposes, as a base for cross-curricular work or a window to future studies, but not in regular class time due to curricular constraints.

FUTURE USES OF CURRICULUM UNIT

Limitations and Recommendations for Future Implementation

Based on immediate posttest evaluation of two small classes, this curriculum unit was effective at teaching foundational geoarchaeology concepts and improving students' awareness of geoarchaeology and interdisciplinarity, through approaches from the field of interdisciplinary education. It has also been modified in response to the data collected. Four teachers were interviewed during the curriculum development stage, and two teachers, along with 30 of their students, participated in the pilot implementation. This is a relatively small sample size, and therefore, conclusions of the curriculum unit's broader applicability are tentative. None of these findings suggests that the curriculum unit should not be applicable elsewhere (i.e., outside of England, with different age groups, etc.); however, it is possible that the results may be specific to these settings. Therefore, care has been taken to describe the curriculum unit characteristics and limitations with as much transparency as possible, and care must also be used to replicate these characteristics or modify them where applicable.

Limitations of curricular measures have been mitigated by triangulating several sources of data used to determine effectiveness, each with differing limiting factors. Observations had to be occasionally bypassed when teachers required assistance from the researcher (coauthor A.J.). The paucity of student answers made it difficult to gauge the direct outputs that the groups were able to accomplish. The quantitative measures of curricular effectiveness utilized, i.e., perception and concept questionnaires, were limited by their length and extent of validation (a pass by one expert geoarchaeologist). In the future, more rigorous measures and wider expert validation (outside the research team) would be beneficial. Student feedback was limited by the fact that the answers were collected in questionnaire form, and therefore, the researcher was unable to further uncover the reasoning behind individual responses. Teacher feedback was again restricted by sample size and, therefore, strongly dependent on teacher background.

The curriculum unit can only be successful when teachers are interested in and comfortable with teaching their students something new, requiring a commitment to

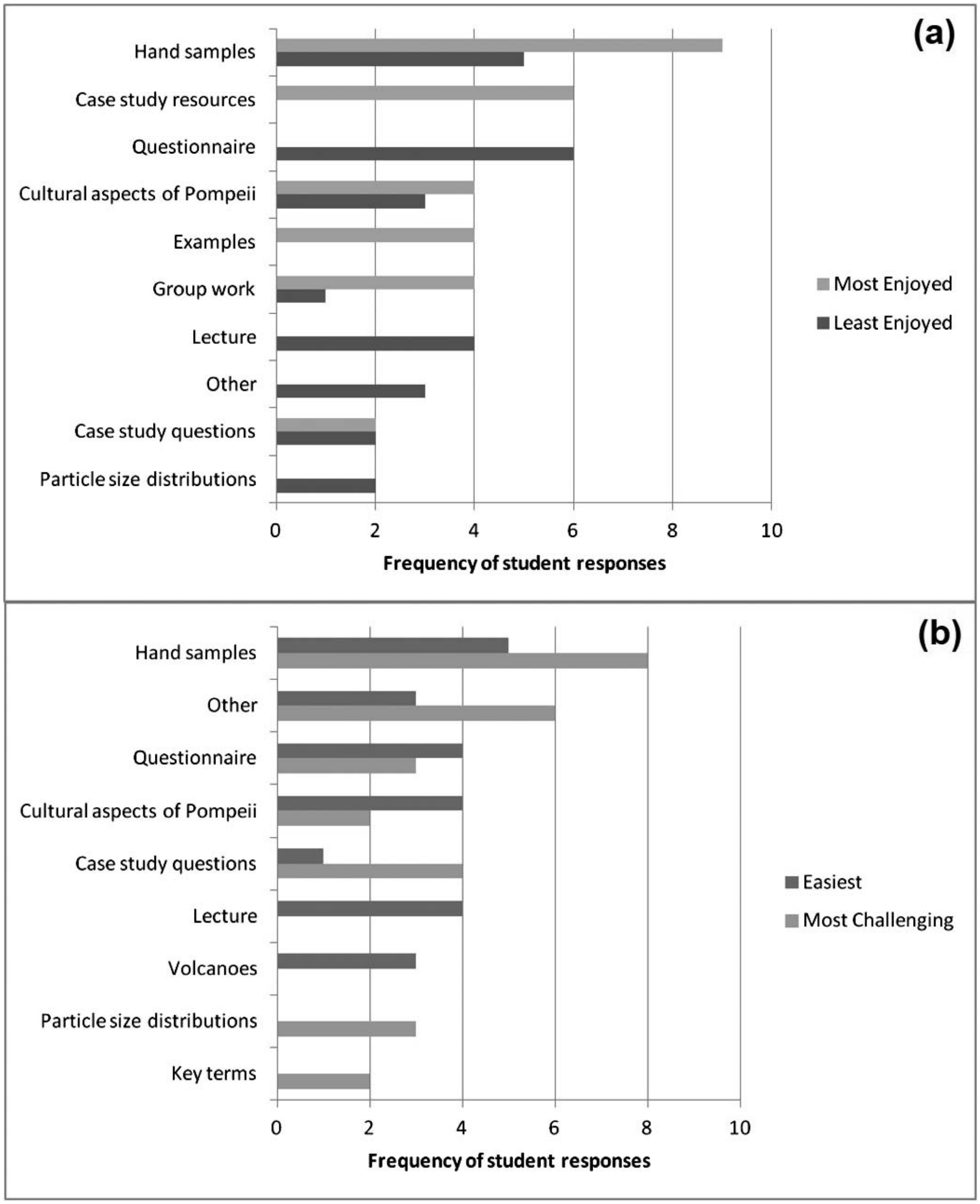

FIGURE 2: (a) Most common student responses on open-ended feedback questions: most and least enjoyed aspects of the curriculum unit. Positive comments were generally associated with the case study questions, and negative comments were associated with the interactive lecture sections. Total number of students = 30. (b) Most common student responses on open-ended feedback questions: easiest and most challenging aspects of the curriculum unit. The interactive lecture sections were more commonly thought of as easy, while the case study questions were perceived as challenging. Perceptions of the difficulty of the hand sample questions were mixed. Total number of students = 30.

learning content and spending some time preparing for instruction. Ideally, the existence of a fully developed structure with supporting documents (including a teaching guide and answer key; see supplemental file 6, which can be found online at http://dx.doi.org/10.5408/14-048s6) will greatly minimize both teacher apprehension and preparation time. It is also hoped that the connections to A-level curricula and other national standards described herein (Table I) will assist in linking the curriculum unit back to required content at the high school level and beyond.

Curriculum Unit Setting

Although the curriculum unit was designed for upper-year high school students (ages 16–17; e.g., A-level, 11th and 12th grade, or 6th and 7th form), teachers indicated that it would also be suitable for lower-year high school students (ages 14–15; e.g., General Certificate of Secondary

Education, or GCSE, 9th and 10th grade, or 4th and 5th form). Additionally, it is expected that the curriculum unit would be useful for first-year postsecondary students, as geoarchaeology is a new topic for most. Potential subjects where the curriculum unit might be implemented include geography, classical civilization/classical studies/world history, and geology/Earth and space science. In middle and high school, the curriculum unit should be connected to national standards and implemented alongside an incentive for students to engage with the material. Otherwise, the curriculum unit could be used for enrichment opportunities with particularly engaged students.

Potential for Evaluation

Though the pilot implementation of the curriculum unit did not involve student evaluation, there are opportunities to do so. The culmination of the curriculum unit is a modified final "jigsaw" (e.g., Bossert, 1988; Stahl, 1994; Weidman and Bishop, 2009) question that is completed in parts individually and synthesized by the group, and it provides the richest opportunity for evaluation. If students were directed to complete the case study questions in more detail, their answers could be evaluated for content. Additionally, with students taking more ownership for their own sections of the synthesis, this modification should also help mitigate the lack of written answers provided.

Implications and Additional Work

One suggestion was not incorporated into the final version of the curriculum unit—the inclusion of embedded questions in the lecture sections. This was done to preserve flexibility and allow for individual teaching style and disciplinary background to be leveraged in different settings. In the future, as more users from a variety of disciplines implement the curriculum unit, questions that they often ask their students within the lecture could be collated into a question bank that would serve as an additional supporting resource for the curriculum unit. Relevant questions could then be chosen and integrated into the lecture sections, perhaps using classroom response systems.

Similar curriculum units could be developed for other interdisciplinary geoscience fields (e.g., geophysics, planetary geology) using the approach taken here. The content was structured by building a separate knowledge foundation before combining disciplines to tackle a question of interest, which was carried out through active, small group–based learning. In this case, this structure was utilized to bridge science and humanities in order to address culturally based questions with Earth Science approaches; however, other contexts could serve different groups of students than are reached by geoarchaeology, such as physics and astronomy (e.g., Thomas et al., 2013). K–12 (primary and secondary school) outreach is a useful venue for building interest in geology, particularly with students that have limited opportunities to explore it (e.g., McGill et al., 2004; Meyers, 2009). Recruitment may also be broadened within the postsecondary setting by introducing and connecting geoscience with other disciplines at the introductory level (e.g., Hoisch and Bowie, 2010).

The interdisciplinary pedagogical structure was not evaluated against another structure. It could be compared with an approach to geoarchaeology that does not separate disciplinary perspectives, or to one that never combines the disciplines. This structure could also be compared to curriculum units from interdisciplinary geoscience fields to see if the results are consistent, i.e., that they are equally successful at improving perceptions of interdisciplinarity and learning interdisciplinary content.

CONCLUSION

Using an iterative, reflective approach, the "Living with Volcanoes" curriculum unit was developed to introduce geoarchaeology and interdisciplinarity to high school students after interviews with teachers from both science and humanities. The curriculum design built upon relevant literature, from geoscience education and interdisciplinary studies, and was refined through pre- and postinstruction interviews with teachers. The curriculum unit was then piloted with one classical civilization and one geography class in northern England, delivered by the teachers of those classes. The pilot studies were observed, and student data regarding knowledge and perceptions of geoarchaeology and interdisciplinarity were collected through pre- and postinstruction questionnaires. Immediately following the delivery of the curriculum unit, teachers provided feedback through postinstruction interviews.

The curriculum unit is effective at teaching foundational concepts of geoarchaeology, as evidenced by an average learning gain of 0.42 on the pre- to postinstruction knowledge questionnaire. Student perspectives on interdisciplinarity became more favorable, as indicated by the pre- and postinstruction perception questionnaire. However, it is unclear whether or not these learning gains and attitudes were retained in the longer term. Observations of the pilot study indicated highly engaged and interested students, as well as slight variations in teaching approaches. These positive results were confirmed by the postinstruction interviews with the teachers involved.

Final revisions were made to the curriculum unit, incorporating student and educator feedback and research findings. It is ready for wider implementation in related topics at middle school, high school, and introductory postsecondary levels, and it is available as supplemental files to this manuscript, online, through the Science Education Resource Center (http://serc.carleton.edu/NAGTWorkshops/environmental/activities/86215.html), or from the corresponding author. Similar approaches may be taken with development of curriculum units for other interdisciplinary geoscience topics, which may prove useful for cross-disciplinary outreach and university recruitment.

Acknowledgments

Thanks go to faculty, staff, and peers at the University of Sheffield for many useful discussions on this work. In particular, we would like to thank Linda Billam and Dr. Jane Rempel for providing college and 6th form contacts. We are grateful to the teachers and students who volunteered their time to be involved in this project and shared valuable insight on the curriculum unit and its development. Thanks also go to Dr. Brendan Duffy for a thoughtful review of an early draft of this manuscript. Comments from two anonymous reviewers, an associate editor, and the editor-in-chief (Dr. Kristen St. John) greatly improved this manuscript. This research was approved by the Human

Ethics Committee in the Department of Archaeology at the University of Sheffield.

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APPENDIX A. Observation Protocol.

Date:
Time:
Location:
Participant number:
Number of students:
Number of groups:
Physical layout of room:

Section	Length (min)	Time (∼/3 min)	Method	Engage	Quest? (Y/N)	Describe
Lecture Pt. 1	Approx.: 15					
	Start:					
	End:					
	Actual:					
Case Study Pt. 1	Approx.: 30					
	Start:					
	End:					
	Actual:					
Lecture Pt. 2	Approx.: 10					
	Start:					
	End:					
	Actual:					
Case Study Pt. 2	Approx.: 30					
	Start:					
	End:					
	Actual:					
Recap	Approx.: 5 Start:					
	End: Actual:					

For each time bracket: assign method (LTell = lecture, Eg = example, MM = multimedia, In = interpretation, Cr = creating), rate engagement (/10 for ppt., / group no. for case study), note any questions asked (teacher or student), and describe (narrative).
Additional notes (continued on back):

APPENDIX B. Pre/postinstruction questionnaire, question format, and associated curriculum unit learning objectives.

Section	Question	Response Format	Learning Objective
Perception	It is useful to approach problems by connecting ideas from multiple disciplines (fields of study).	5 point Likert scale	Explore the benefits and challenges of interdisciplinarity. (evaluation)
Perception	It is time-consuming to approach problems by connecting ideas from multiple disciplines.	5 point Likert scale	Explore the benefits and challenges of interdisciplinarity. (evaluation)
Perception	I can imagine connections between archaeology and other disciplines (aside from geography/ geology).	5 point Likert scale	Explore the benefits and challenges of interdisciplinarity. (evaluation)
Perception	Archaeology is made stronger when it is connected to other disciplines.	5 point Likert scale	Explore the benefits and challenges of interdisciplinarity. (evaluation)
Perception	I think I have a good idea about what it means to study geoarchaeology.	5 point Likert scale	Introduce geoarchaeology and its foundational concepts. (knowledge)
Perception	I think that geoarchaeology would be fun to study.	5 point Likert scale	N/A
Concept	Give **two** examples of the type of information that come from the study of artifacts from an archaeological site.	Open-ended	Describe some archaeological approaches (and how geoarchaeology builds on them). (comprehension)
Concept	Name **two** differences between **shield volcanoes** and **stratovolcanoes** (complex volcanoes). Which one is more explosive?	Open-ended	Describe two major types of volcanoes and some related volcanic deposits. (knowledge)
Concept	**Compare and contrast** some different types of information that **geographers** and **archaeologists** might want to study on a site that has been preserved by volcanic eruption. **Give one example** of how they could collaborate to better understand the site.	Open-ended	Compare and contrast geographical and archaeological settings and materials. (evaluation); describe some archaeological approaches and how geoarchaeology builds on them. (comprehension)
Feedback[1]	Which part of the lesson did you enjoy the **most**? Why?	Open-ended	N/A
Feedback[1]	Which part of the lesson did you enjoy the **least**? Why?	Open-ended	N/A
Feedback[1]	Which part of the lesson did you find the **easiest**? Why?	Open-ended	N/A
Feedback[1]	Which part of the lesson did you find the **most challenging**? Why?	Open-ended	N/A

[1]Question only asked on postinstruction questionnaire.