RESEARCH ARTICLE

VOLCANICA

A summary of peer-reviewed resources for teaching volcanology in higher education

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Submitted: 2022-12-15 | Accepted: 2023-07-05 | Published: 2023-08-10

Editor: J. I. Farquharson | Typesetter: J. I. Farquharson

Abstract

Here, we summarise and categorise the volcanology learning activities identified and described in a systematic literature review of volcanology higher education [a companion article; Dohaney et al. 2023]. We share the 47 peer-reviewed articles organised by useful categories, such as educational level, mode and setting of learning, volcanic phenomena, and skills learned in the curricula for easier use and navigation by volcanology instructors. Based on the claims made in the peer-reviewed resources, considerations and suggestions for improved volcanology teaching are included, e.g. exploring authentic field-based experiences, local sites, or simulated demonstrations of volcanic phenomena. To support use of these curricula, we provide suggestions for adapting the resources and highlight additional online catalogues that house useful and engaging volcanology teaching materials.

Non-technical summary

Ici, nous résumons et catégorisons les activités pédagogiques de volcanologie identifiées et décrites dans une revue systématique de la littérature de l'enseignement supérieur de volcanologie [un article d'accompagnement; Dohaney et al. 2023]. Nous partageons les 47 articles évalués par des pairs pour une utilisation et une navigation plus faciles par les instructeurs de volcanologie. Nous organisons les articles par catégories utiles, telles que le niveau d'enseignement, le mode et le cadre d'apprentissage, les phénomènes volcaniques et les compétences acquises dans les programmes. Sur la base des affirmations faites dans les ressources étudiées ici, nous incluons des considérations et des suggestions pour améliorer l'enseignement de la volcanologie; par exemple, l'exploration d'expériences authentiques sur le terrain, l'utilisation de sites locaux ou des démonstrations simulées de phénomènes volcaniques. Pour soutenir l'utilisation de ces programmes, nous fournissons des suggestions pour adapter les ressources et mettons en évidence des catalogues en ligne supplémentaires qui contiennent du matériel pédagogique de volcanologie utile et engageant.

Keywords: Higher education; Systematic review; Volcanology; Teaching; Learning.
This article is a companion to Dohaney et al. [2023] doi:10.30909/vol.06.02.221252

1 Introduction

Modern life at universities and colleges is a busy landscape, demanding much time from staff and students alike. Volcanology instructors in higher education are tasked with delivering engaging and effective learning and teaching in increasingly challenging time pressures. Recently, a growing number of geoscientists have become interested and engaged in research-informed learning and teaching [St. John et al. 2013], reading educational research, consulting with education specialists, or conducting their own scholarship in learning and teaching [Jolley et al. 2022]. This movement towards research-informed teaching demonstrates the value that our community places on improvement and inquiry into higher education [Lukes et al. 2015]. Nonetheless, a key problem faced by instructors is finding appropriate existing evidence-based learning and teaching resources, a potentially time-consuming task. Without being able to spend the time to locate such resources, conventional curricula may be recycled and maintained, and students may miss out on the potentially innovative, effective, and engaging activities that volcanology instructors are creating in our global teaching community. Here, we aim to ameliorate this problem and provide instructors with a curated collection of resources, which is commonly requested by volcanology instructors [Jolley et al. 2022].

In this article, we present 47 peer-reviewed resources derived from a systematic mapping of volcanology higher education literature (companion article, see Dohaney et al. [2023]). Our aim in this work was to provide a succinct overview of the key peer-reviewed resources available for the community for use and adaption by volcanology instructors. The purpose is not to assess the quality of the literature or to provide instructions on use of specific activities, but to present the catalogue of peer-reviewed resources available and descriptions of those pieces for easier navigation. Importantly, these resources do not represent all of the existing innovative and effective existing teaching materials but are those that have been peer reviewed and published.

2 Methodology

The articles included here were identified and characterised in a systematic mapping of the volcanology higher education literature. A detailed guide to the methodology used in that study are found in the main text and appendix of the companion article, Dohaney et al. [2023]. Here is a summary of the methodology used:

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- The knowledge base was **searched** for all relevant literature using keywords and known databases;

- The literature was **screened** and **appraised** [e.g. Borrego et al. 2014] against inclusion and exclusion criteria (e.g. literature must be peer-reviewed, literature must include volcanology concepts) removing all literature that didn't align with our research questions;

- The collection of literature was then read and **coded** for specific themes, such as bibliographic information, volcanic phenomena, and curricula descriptions;

- All codes and themes were refined, **categorised**, and counted and tabulated into succinct, descriptive summaries of information.

A detailed description of the results of that study including the research findings and their implications are found in Dohaney et al. [2023], whereas this article is about the curriculum resources available in that collection that may be useful for instructors.

3 Teaching Resources

The systematic review (articles published before 2020) found 47 pieces of literature that included volcanology curricula from a breadth of higher education course types and sizes, with broad applicability across the sub-disciplines of the geosciences. Table 1 displays all of the 47 pieces, their titles and authors, with key curricula information such as the level of higher education, the educational setting, and modes of learning. Full citation and bibliographic information can be found in Appendix A. All of the tables are organised in a manner to allow readers to pick the literature that is best suited to their needs and context. For example, a teacher wanting to find modules for an introductory geology course could look at the records with 'introductory', 'classroom' labels in Table 1. Visual displays of the categorical data presented within each table is also included in Figure 1, to assist in understanding of the information. Most of the information provided is also referenced by a record number. A record number is a unique number (ranging from 1–2507) that we assigned to each unique piece of literature identified during the search phase of the systematic review. These numbers allow us to refer to a piece of literature quickly and clearly (See Table 2–4).

The level of education of the curricula (Figure 1A) were roughly evenly split between all levels (13 in total, 27 % of the literature), introductory (12, 25.5 %; lower division courses usually first and second year), upper-level (12, 25.5 %; upper division courses usually third or fourth year, including post-graduate learning), and not described (10, 21 %). The setting for learning (Figure 1B) was classroom (26, 55 %), laboratory (14, 30 %), field (13, 27 %), offsite (2, 4 %), outdoor (2, 4 %), not described (5, 11 %), noting that curricula were sometimes reported by the authors to be suited to more than one setting. The mode for learning (Figure 1C) was overwhelmingly in-person (46, 98 %) with some curricula online (8, 17 %), also noting that some curricula were reportedly delivered in both modes (7, 15 %).

Table 2 includes a list of the literature (labelled by record number) organised by the most commonly mentioned activities (out of a total of 74 unique activities) that learners engage in described within the curriculum (Figure 1D). These included simulation (15 articles or 32 % of the literature mentioned simulations), lectures (12; 26 %), readings (10; 21 %), field trips (9; 19 %), role-play (9; 19 %), modelling (8, 17 %), experiments (7, 15 %), imagery (digital and hardcopy; 6; 13 %), videos (5, 11 %), research project (5, 11 %), and hand sample analysis (5; 11 %). Note that the curricula in the literature often used multiple types of activities, e.g. field trips that included research, modelling, lectures, and readings.

Table 3 includes a list of the literature organised by the most commonly mentioned volcanic phenomena (out of a total of 252 unique volcanic phenomena reported). The phenomena (Figure 1E) included: eruptions (31, 66 % of the articles included eruptions), lava and lava flows (24, 51 %), hazards (19, 40 %), gas(es) (15, 32 %), human and social impacts (14, 30 %), ash and ashfall (14, 30 %), earthquake or seismic phenomena (14, 30 %), pyroclastic flows (13, 28 %), and ground deformation (9, 19 %).

The final list, in Table 4, is organised by the categories of skills that students might learn. The most commonly reported categories of geosciences-specific skills (Figure 1F) included mapping and field skills (15, 32 %), volcanic monitoring and forecasting (12, 25.5 %), remote sensing (9, 19 %), and volcanic hazard management (7, 15 %). The most commonly reported categories of transferable skills (i.e., skills that may be applied across situations and disciplines; Figure 1G) included research (27, 57 %), communication (19, 40 %), teamwork (15, 32 %), quantitative skills (e.g. computational or data processing skills; 14, 30 %), project management (8, 17 %), and personal development (6, 13 %).

4 Discussion

There are several key areas emerging from the systemic review and from this resources-focussed article that we feel are valuable for volcanology educators. The first section will discuss key considerations and suggestions that are derived from the claims made by authors in the 47 pieces of literature. To support readers in making use of the resources we present here, the second section will provide a pathway of selecting and adapting existing teaching resources, drawing upon foundational educational practices used across the disciplines. In the final section, we will provide existing volcanology teaching databases where educators might locate additional curricula for their courses.

4.1 Considerations and suggestions for improving volcanology teaching practices.

In Dohaney et al. [2023], we organised the claims, which are statements backed by some form of empirical data, into themes and looked at trends and frequencies of those claims. Though we did not assess the quality or trustworthiness of the claim statements, there are some claim categories that are more prevalent than others, indicating that volcanology education researchers may be more likely to select these approaches. If we consider the collection of volcanology teaching described

Table 1: Volcanology higher education literature, organised by record number, including level of education, settings, and mode of learning. Each of the pieces of literature cited below is cited in Appendix A, with DOI and other permalinks. Record numbers are unique numbers (ranging from 1–2507) that we assigned to each piece of literature identified during the search phase of the systematic review.

Record	Title (Citation)	Level	Setting	Mode
26	Using near-real-time monitoring data from Pu'u 'Ō'ō vent at Kīlauea volcano for training and educational purposes [Teasdale et al. 2015]	All levels	Classroom	Online; In-person
100	Exploring geology on the world-wide web: Volcanoes and volcanism [Schimmrich and Gore 1996]	Not described	Not described	Online
119	A capstone course in Ecuador: The Andes/Galapagos volcanology field camp program [Kelley et al. 2017]	Upper-level	Field	In-person
176	A service-learning project on volcanoes to promote critical thinking and the earth science literacy initiative [Nunn and Braud 2013]	Introductory	Classroom; Offsite	In-person
178	Improving decision making skill using an online volcanic crisis simulation: Impact of data presentation format [Barclay et al. 2011]	Introductory	Classroom; Laboratory	In-person
209	The InVEST volcanic concept survey: Assessment of conceptual knowledge about volcanoes among undergraduates in entry-level geoscience courses [Parham Jr 2009]	Introductory	Classroom	In-person
274	Using geodynamics data base in a volcanology course [Bhatia and Corgan 1996]	Upper-level	Classroom; Laboratory	In-person
349	Field exercises in the Pinacate volcanic field, Mexico: An analog for planetary volcanism [Williams et al. 2011]	Not described	Field	In-person
385	A titration technique for demonstrating a magma replenishment model [Hodder 1983]	Not described	Laboratory	In-person
388	Learning geomorphology using aerial photography in a web-facilitated class [Palmer 2013]	All levels	Laboratory	Online; In-person
389	Bringing the field into the classroom by using dynamic digital maps to engage undergraduate students in petrology research [Boundy and Condit 2004]	Not described	Classroom; Laboratory	In-person
434	Using free digital data to introduce volcanic hazards [Abolins 1997]	Introductory	Laboratory	In-person
445	Magma ascent rates from mineral reaction rims and extension to teaching about volcanic hazards [Farver and Brabander 2001]	All levels	Laboratory	In-person
576	Does students' source of knowledge affect their understanding of volcanic systems? [Parham et al. 2011]	Introductory	Classroom	In-person
713	V-Volcano: Addressing students' misconceptions in earth sciences learning through virtual reality simulations [Boudreaux et al. 2009]	Introductory	Classroom	In-person
754	Bringing the mountain to the student: Developing a fully integrated online volcano module [Turney et al. 2004]	Introductory	Laboratory	Online; In-person
1063	Training in crisis communication and volcanic eruption forecasting: Design and evaluation of an authentic role-play simulation [Dohaney et al. 2015]	Upper-level	Classroom; Field	In-person
1088	Volcanoes in the classroom: A simulation of an eruption column [Harpp et al. 2005]	All levels	Outdoor	In-person
1171	A geology-focused virtual field trip to Tenerife, Spain [Lang et al. 2012]	All levels	Classroom; Laboratory	Online; In-person
1223	Trashcano: Developing a quantitative teaching tool to understand ballistics accelerated by explosive volcanic eruptions [Wadsworth et al. 2018]	All levels	Outdoor	In-person
1274	Innovative teaching methods and strategies in civil, hydrology and geological engineering in volcanic subjects [Santamarta et al. 2013]	Not described	Classroom; Laboratory; Offsite	Online; In-person
1298	An exercise in forecasting the next Mauna Loa eruption [Mattox 1999]	Not described	Not described	In-person
1375	Simulating a volcanic crisis in the classroom [Harpp and Sweeney 2002]	All levels	Classroom	In-person
1381	NASA volcanology field workshops on Hawai'i: Part 1. Description and history [Rowland et al. 2011]	All levels	Field	In-person
1443	Interactive computer modeling of social and scientific issues related to volcanic hazards [Bursik et al. 1994]	Introductory	Laboratory	In-person
1554	Integrating undergraduate education and scientific discovery through field research in igneous petrology [Gonzales and Semken 2006]	Upper-level	Classroom; Field	In-person
1631	A comparative study of field inquiry in an undergraduate petrology course [Gonzales and Semken 2009]	Upper-level	Classroom; Field	In-person
1657	A videotape short course on volcanic rock textures [Chesner and Rose 1987]	All levels	Classroom	In-person

Continued on next page.

Table 1 [cont.]: Volcanology higher education literature, organised by record number, including level of education, settings, and mode of learning. Each of the pieces of literature cited below is cited in Appendix A, with DOI and other permalinks. Record numbers are unique numbers (ranging from 1–2507) that we assigned to each piece of literature identified during the search phase of the systematic review.

Record	Title (Citation)	Level	Setting	Mode
1747	Teaching volcanic hazard management and emergency management concepts through role-play: The science behind the Auckland volcanic field simulation [Fitzgerald et al. 2016]	Upper-level	Classroom; Field	In-person
1792	The InVEST volcanic concept survey: Exploring student understanding about volcanoes [Parham et al. 2010]	Introductory	Classroom	In-person
1825	A modified jigsaw-type exercise for studying volcanic landforms [Whittecar 2000]	Not described	Classroom	In-person
1947	VLP Simulation: An interactive simple virtual model to encourage geoscience skill about volcano [Hariyono et al. 2017]	Upper-level	Not described	In-person
2065	Telepresence-enabled remote fieldwork: Undergraduate research in the deep sea [Stephens et al. 2016]	All levels	Classroom; Field	Online; In-person
2082	Field geophysics class at Volcan Tungurahua, Ecuador [Johnson and Ruiz 2009]	Upper-level	Field	In-person
2179	Maps, plates, and Mount Saint Helens [Lary and Krockover 1987]	Not described	Classroom	In-person
2193	Teaching hazard-mitigation education in a liberal-arts college [Bladh 1990]	Upper-level	Classroom; Laboratory	In-person
2232	Active learning strategies for constructing knowledge of viscosity controls on lava flow emplacement, textures, and volcanic hazards [Edwards et al. 2006]	Introductory	Laboratory	In-person
2344	The "Holey Tour" planetary geology field trip, Arizona [Greeley 2011]	Upper-level	Field	In-person
2363	Visualizing volcanic processes in SketchUp: An integrated geo-education tool [Lewis and Hampton 2015]	Not described	Field	In-person
2497	Simulation of physical processes in environmental geology laboratories [Hodge et al. 1995]	Introductory	Laboratory	In-person
2498	Using a decision-assessment matrix in volcanic hazards management [Hodder 1999]	Introductory	Classroom	In-person
2499	Real world-based immersive Virtual Reality for research, teaching, and communication in volcanology [Tibaldi et al. 2020]	Upper-level	Classroom; Field	In-person
2503	The educational effectiveness of computer-based instruction [Renshaw and Taylor 2000]	All levels	Not described	In-person
2504	Learning volcanology: Modules to facilitate problem solving by undergraduate volcanology students [Connor and Vacher 2016]	Not described	Classroom	In-person
2505	Using role-play to improve students' confidence and perceptions of communication in a simulated volcanic crisis [Dohaney et al. 2017]	Upper-level	Classroom; Field	In-person
2506	Evaluation of student learning, self-efficacy, and perception of the value of geologic monitoring from Living on the Edge, an InTeGrate curriculum module [Teasdale et al. 2018]	All levels	Classroom	In-person
2507	Introducing geoscience students to numerical modeling of volcanic hazards: The example of `Tephra2` on `vHub.org` [Courtland et al. 2012]	All levels	Not described	Online; In-person

and reviewed, holistically, we can discern some considerations for teachers of volcanology in higher education that may lead to 'good' practices. The considerations listed below are backed by the broader geoscience education research body of knowledge. However, these considerations are not all robustly tested and are drawn from dominantly context-specific studies and may not be generalisable to a wider population of learners and settings. Nonetheless, we feel these considerations may aid practitioners towards improved teaching by offering promising practices and curricula that may be intentionally adapted to meet student and instructor needs. Based on our review, when designing and delivering volcanology learning, educators might consider …

- exploring authentic field-based opportunities to increase engagement and enable cognitive or affective learning [see Gonzales and Semken 2006; Elkins and Elkins 2007; Gonzales and Semken 2009; Williams et al. 2011; Stephens et al. 2016];

- incorporating locally or globally significant sites of interest into your teaching to increase student engagement and connections with volcanic sites [see Semken et al. 2017; Jolley et al. 2018];

- simulating volcanic phenomena through demonstrations and role-plays to support skills development, engagement, and enjoyment of volcanology processes [see Harpp and Sweeney 2002; Barclay et al. 2011; Dohaney et al. 2015; Teasdale et al. 2015; Dohaney et al. 2017; Wadsworth et al. 2018];

Table 2: Literature organised by the most commonly mentioned curriculum activity types

Activity type		Record numbers
simulation	(15)	26; 178; 389; 713; 1063; 1088; 1223; 1274; 1375; 1443; 1747; 1947; 2497; 2503; 2505
lectures	(12)	178; 274; 388; 1063; 1171; 1381; 1554; 1631; 2193; 2504; 2505; 2507
readings	(10)	119; 389; 445; 1063; 1274; 1375; 1381; 1554; 1631; 2193
role-play	(9)	26; 178; 1063; 1375; 1443; 1747; 2503; 2505; 2506
field trips	(9)	100; 119; 349; 388; 754; 1171; 1381; 2082; 2344
modeling	(8)	385; 1223; 1443; 2082; 2363; 2497; 2499; 2507
experiments	(7)	385; 445; 713; 1088; 1223; 2232; 2497
imagery	(6)	26; 100; 119; 349; 434; 1381
videos	(5)	1088; 1171; 1274; 1375; 1657
research project	(5)	274; 389; 1554; 1631; 2065
hand sample analysis	(4)	445; 1274; 1554; 1631

Table 3: Literature organised by the most commonly mentioned volcanic phenomena

Volcanic phenomena		Record numbers
eruption(s)	(31)	26; 178; 209; 274; 385; 388; 389; 445; 576; 713; 1063; 1088; 1223; 1298; 1375; 1381; 1443; 1631; 1747; 1947; 2065; 2082; 2232; 2344; 2363; 2497; 2499; 2503; 2505; 2506; 2507
lava & lava flow(s)	(24)	26; 119; 176; 209; 349; 389; 434; 713; 1171; 1223; 1298; 1381; 1443; 1657; 1747; 1792; 1825; 2193; 2232; 2344; 2363; 2498; 2497; 2504
hazard(s)	(19)	26; 100; 119; 176; 209; 434; 445; 576; 713; 1063; 1298; 1375; 1443; 1747; 1947; 2193; 2503; 2505; 2507
gas(es)	(15)	178; 209; 713; 1063; 1088; 1375; 1443; 1747; 1792; 1947; 2065; 2497; 2503; 2505; 2506
human & social impact(s)	(14)	100; 176; 445; 576; 713; 754; 1063; 1375; 1443; 1747; 2193; 2499; 2505; 2507
ash & ashfall	(14)	100; 178; 209; 713; 1063; 1631; 1657; 1747; 1792; 2193; 2344; 2498; 2505; 2506
earthquake(s) or seismic	(14)	26; 178; 274; 1063; 1298; 1375; 1443; 1747; 1947; 2065; 2082; 2503; 2505; 2506
pyroclastic flow(s)	(13)	119; 176; 349; 434; 713; 1171; 1381; 1443; 1657; 1747; 1792; 2193; 2497
ground deformation	(9)	26; 178; 1063; 1375; 1443; 1747; 1947; 2503; 2505

Table 4: Literature organised by geosciences-specific and transferable skill categories

Skills		Record numbers
Geosciences-specific		
Mapping and field skills	(15)	119; 274; 349; 389; 1088; 1171; 1375; 1381; 1554; 1631; 2179; 2363; 2344; 2497; 2499
Volcanic monitoring and forecasting	(12)	26; 100; 119; 178; 1063; 1223; 1298; 1375; 1747; 2503; 2505; 2507
Remote sensing	(9)	100; 119; 349; 388; 434; 1171; 1381; 1825; 2363
Volcanic hazards management	(7)	445; 1063; 1375; 1443; 1747; 2193; 2505
Transferable		
Research	(27)	100; 119; 274; 349; 385; 389; 445; 754; 1063; 1088; 1171; 1223; 1298; 1375; 1381; 1443; 1554; 1631; 1747; 1825; 2065; 2082; 2193; 2363; 2497; 2503; 2504
Communication	(19)	26; 176; 274; 385; 445; 1063; 1375; 1443; 1554; 1631; 1747; 1825; 2065; 2082; 2193; 2504; 2505; 2506; 2507
Teamwork	(15)	119; 176; 389; 1063; 1088; 1171; 1375; 1443; 1554; 1631; 1747; 1825; 2505; 2506; 2507
Quantitative	(14)	100; 385; 388; 389; 445; 1088; 1223; 1375; 2082; 2232; 2363; 2498; 2504; 2507
Project management	(8)	176; 389; 1063; 1375; 1443; 1554; 1631; 2498
Personal development	(6)	176; 389; 754; 1375; 1381; 1554

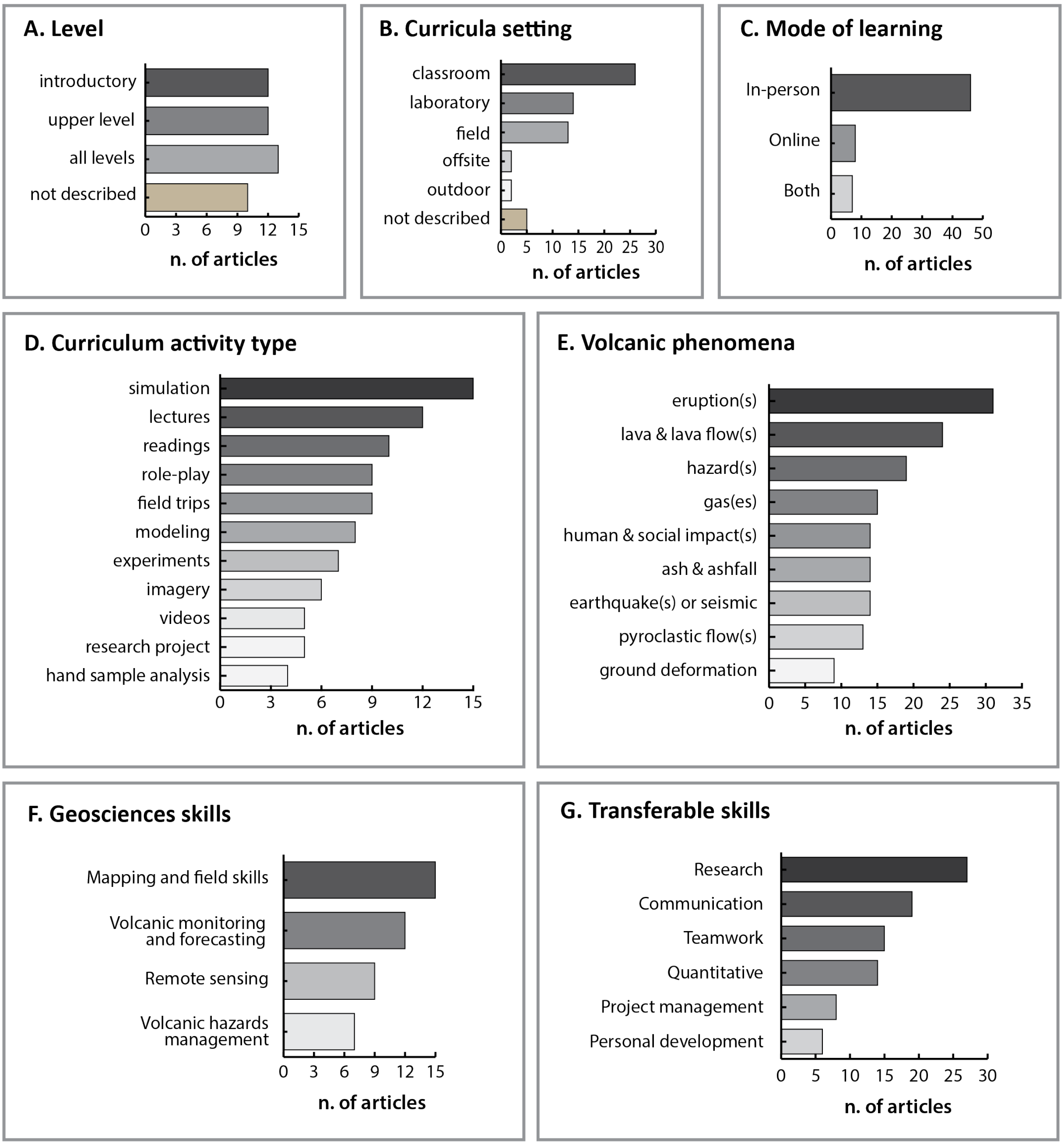

Figure 1: Bar charts illustrating the number of articles coded to a specific category: [A] Level of education that the curriculum is suited to; [B] Setting of the curriculum; [C] Mode of learning; [D] Curriculum activity type; [E] Volcanic phenomena covered in the curriculum; [F] Geosciences skills learned in the curriculum; [G] Transferable skills learned in the curriculum.

- the importance of the student demographics, academic background, and contexts when designing learning [O'Connell et al. 2022]. How might student conceptions of volcanoes differ? [see Parham et al. 2010; 2011];

- exploring the technical and digital competencies important to volcanology learning [see Renshaw and Taylor 2000; Boundy and Condit 2004; Barclay et al. 2011; Palmer 2013; Lewis and Hampton 2015].

4.2 Making use of existing resources

As learning is situated [Lave and Wenger 1991], taking a curriculum built for a specific group of learners and setting and adapting it for your own curriculum will always require some adaption, time, and effort. We suggest starting with these key questions to select the right resource and ensure that the curriculum matches your needs:

- What are the learning outcomes (e.g. Bloom's taxonomy [Bloom et al. 1956]) that you intend for your students, and do those match the intended learning outcomes of the activity you have selected?

- What skills are needed (prerequisites) prior to the activities and what skills do you hope to enhance by adding this resource?

- Where does this activity fit into the sequence of your course?

- Realistically, how much student and instructor time and workload does this new activity take and does it fit within your current curriculum design?

- Do you have the needed physical and digital infrastructure to deliver the new materials and/or to re-develop the new materials?

If you have decided that the resource is a good fit for your curriculum, then you can move onto adaption. A process of redesign can take many forms, but here is a suggested pathway:

1. Adjust the activities to suit the learners' capabilities, balancing the challenge they face with their prerequisite capabilities. You might need to:

a. Add new content, preparation materials, and activities to upskill them [Dohaney et al. 2015];

b. Remove challenging components that are too advanced for your learners.

2. Scale up or scale back the duration and complexity of the activities to suit your course schedule and desired depth (i.e. Is this something you want to dedicate several weeks to? Or only one or two classes?);

3. Where possible, add or increase the connection of the activity with your local context [e.g. Jolley et al. 2018]—can you replicate the same activity using your local geology and local sites of interest?

4. Consider the mode (online, in-person, blended, or hybrid) and match the mode of learning to the context and resources available;

5. Where possible, get support from your colleagues, education specialists, or academic developers [Jolley et al. 2022].

Though these considerations and suggestions are general in nature, we feel that educators can use these prompts to support their decision making during the beginning phases of curriculum development. For readers who are interested in a much more detailed exploration of the curriculum design and development process, we recommend using Wiggins and McTighe [2005] 'Understanding by Design' design framework.

4.3 Other sources of volcanology higher education curricula

The literature included here consists of all the currently available (as of 2020) published peer-reviewed resources and does not represent the entirety of volcanology teaching resources. Here we describe other sources of volcanology higher education curricula that are available online and in the literature.

In Jolley et al. [2022], a survey of 55 volcanology instructors found that when teaching educators commonly used: the academic (discipline) literature (47), inherited teaching materials (41), textbooks (39), government web resources (30) while fewer included online resource collections like vHub[*] (17; [vHub 2022]) and SERC[†] (Science Education Resource Centre at Carleton College; 12). The systematic review [Dohaney et al. 2023] did not include textbooks, government webpages or other non-empirical sources of information, but will be a good place to find valuable teaching materials and some of the results are summarised in Figure 1.

vHub and SERC are both larger databases with volcanology teaching materials included within. A simple search of SERC's 'Teach the Earth' catalogue (search "volcano") results in 564 page matches and 156 activities (searched on Nov 16, 2022); additionally, they have a dedicated Site Guide for volcanoes [SERC 2022] which is peer-reviewed by educators. vHub has a collection of 62 educational materials (searched on Nov 16, 2022). These online collections may be useful to readers searching for new curricula to incorporate into their courses. Aside from databases, many universities host their own volcanology education resources, such as Oregon State University[‡], University of Rhode Island's virtual field trips[§] and full open education edX courses[¶] such as the University of Canterbury's "Volcanology field science and society" and "Volcanic hazards" and University of Iceland's "Monitoring Volcanoes and Magma Movement".

As the systematic review did not include recent publications from 2021, 2022, and 2023, we performed a brief database search and found several recent articles that may be useful for some readers. Namely, emergent topics such as volcanology virtual field trips [e.g. Watson et al. 2022], volcano videogames [McGowan and Scarlett 2021; McGowan and Alcott 2022], and online teaching [Jones 2022]. The most common publishing outlets for new volcanology education work appear to be the *Journal of Geoscience Education*, *Volcanica*, and others listed in Dohaney et al. [2023]. Recent conference presentations relevant to volcanology education can be found at the annual Geological Society of America, American Geophysical Union, European Geosciences Union meetings as well as the biennial Cities on Volcanoes and International Association for Volcanology and Chemistry of the Interior meetings.

5 Conclusions

The key aim of this article was to present the collection of peer-reviewed teaching resources included in a systematic review of the volcanology higher education literature and provide categorisation of those resources. The resources are organised by level of education, mode and setting of learning, as well as the most commonly mentioned curriculum activity type, volcanic phenomena, and skills for easier navigation to the reader. Based upon the claims made in the literature review, key considerations and suggestions were provided such

[*] https://theghub.org/groups/v/
[†] https://serc.carleton.edu/index.html
[‡] https://volcano.oregonstate.edu/
[§] https://volcano.uri.edu/index.html
[¶] https://www.edx.org/

as exploring authentic field-based experiences, incorporating local geologic sites, and simulating volcanic phenomena to improve student learning and enjoyment. To support practical use of the resources, we included a series of questions and prompts on selecting and adapting curriculum, and we also highlight two additional existing online catalogues of teaching materials (SERC and vHub).

It is worth repeating that the quality of the educational literature presented here was not assessed, for a variety of reasons. There is likely a wide range of effective and engaging volcanology teaching being delivered worldwide, but without clear reporting and sharing of this information, we are limited to building upon what is available. We are encouraged by the growing interest in volcanology higher education, and so we invite educators and researchers to tackle this challenge of investigating and evaluating student and instructor experiences so that the community might uplift our delivery of engaging and effective volcanology learning. Detailed advice on designing and reporting volcanology higher education work is included in Dohaney et al. [2023]. An up-to-date version of the volcanology higher education literature catalogue is published on vHub (https://theghub.org/resources/4963), including new articles that are added since this work was completed.

Author Contributions

All four authors wrote and edited the manuscript and completed the systematic literature review analysis together.

Acknowledgements

Thank you to all the teachers and researchers who spent their time writing and sharing their ideas about teaching volcanology. Thank you to the Volcanica editor and reviewer for suggesting a new article should be written, and for the research team for enduring a long writing and editing process. Kennedy would like to acknowledge MBIE Endeavour funding ECLIPSE program.

Data Availability

An up-to-date version of the volcanology higher education literature catalogue will be published on vHub (https://theghub.org/resources/4963), including new articles that are added since this work was completed.

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References

Barclay, E. J., C. E. Renshaw, H. A. Taylor, and A. R. Bilge (2011). "Improving Decision Making Skill Using an Online Volcanic Crisis Simulation: Impact of Data Presentation Format". *Journal of Geoscience Education* 59(2), pages 85–92. DOI: 10.5408/1.3543933.

Borrego, M., M. J. Foster, and J. E. Froyd (2014). "Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields". *Journal of Engineering Education* 103(1), pages 45–76. DOI: 10.1002/jee.20038.

Boundy, T. M. and C. Condit (2004). "Bringing the Field into the Classroom by Using Dynamic Digital Maps to Engage Undergraduate Students in Petrology Research". *Journal of Geoscience Education* 52(4), pages 313–319. DOI: 10.5408/1089-9995-52.4.313.

Dohaney, J., E. Brogt, B. Kennedy, T. M. Wilson, and J. M. Lindsay (2015). "Training in crisis communication and volcanic eruption forecasting: design and evaluation of an authentic role-play simulation". *Journal of Applied Volcanology* 4(1). DOI: 10.1186/s13617-015-0030-1.

Dohaney, J., E. Brogt, T. M. Wilson, and B. Kennedy (2017). "Using Role-Play to Improve Students' Confidence and Perceptions of Communication in a Simulated Volcanic Crisis". *Observing the Volcano World*, pages 691–714. DOI: 10.1007/11157_2016_50.

Dohaney, J., A. Jolley, B. Kennedy, and A. Watson (2023). "A systematic review of volcanology learning and teaching in higher education". *Volcanica* 6 (2), pages 221–252. DOI: 10.30909/vol.06.02.221252.

Elkins, J. T. and N. M. Elkins (2007). "Teaching Geology in the Field: Significant Geoscience Concept Gains in Entirely Field-based Introductory Geology Courses". *Journal of Geoscience Education* 55(2), pages 126–132. DOI: 10.5408/1089-9995-55.2.126.

Gonzales, D. and S. Semken (2006). "Integrating Undergraduate Education and Scientific Discovery Through Field Research in Igneous Petrology". *Journal of Geoscience Education* 54(2), pages 133–142. DOI: 10.5408/1089-9995-54.2.133.

Harpp, K. S. and W. J. Sweeney (2002). "Simulating a Volcanic Crisis in the Classroom". *Journal of Geoscience Education* 50(4), pages 410–418. DOI: 10.5408/1089-9995-50.4.410.

Jolley, A., E. Brogt, B. M. Kennedy, S. J. Hampton, and L. Fraser (2018). "Motivation and Connection to Earth on Geology Field Trips in New Zealand: Comparing American Study Abroad Students with Local Undergraduates". *Frontiers: The Interdisciplinary Journal of Study Abroad* 30(3), pages 72–99. DOI: 10.36366/frontiers.v30i3.423.

Jolley, A., J. Dohaney, and B. Kennedy (2022). "Teaching about volcanoes: Practices, perceptions, and implications for professional development". *Volcanica* 5(1), pages 11–32. DOI: 10.30909/vol.05.01.1132.

Lewis, G. and S. Hampton (2015). "Visualizing volcanic processes in SketchUp: An integrated geo-education tool". *Computers & Geosciences* 81, pages 93–100. DOI: 10.1016/j.cageo.2015.05.003.

Lukes, L. A., N. D. LaDue, K. A. Cheek, K. Ryker, and K. St. John (2015). "Creating a Community of Practice Around Geoscience Education Research: NAGT-GER". *Journal of Geoscience Education* 63(1), pages 1–6. DOI: 10.5408/1089-9995-63.1.1.

Parham, T. L., C. Cervato, W. A. Gallus, M. Larsen, J. Hobbs, P. Stelling, T. Greenbowe, T. Gupta, J. A. Knox, and T. E. Gill (2010). "The InVEST Volcanic Concept Survey: Exploring Student Understanding About Volcanoes". *Journal of Geoscience Education* 58(3), pages 177–187. DOI: 10.5408/1.3544298.

Semken, S., E. G. Ward, S. Moosavi, and P. W. U. Chinn (2017). "Place-Based Education in Geoscience: Theory, Research, Practice, and Assessment". *Journal of Geoscience Education* 65(4), pages 542–562. DOI: 10.5408/17-276.1.

St. John, K., D. Dickerson, and K. S. McNeal (2013). "Guide to aspiring authors". *Journal of Geoscience Education* 61(3), pages 253–255.

Stephens, A. L., A. Pallant, and C. McIntyre (2016). "Telepresence-enabled remote fieldwork: undergraduate research in the deep sea". *International Journal of Science Education* 38(13), pages 2096–2113. DOI: 10.1080/09500693.2016.1228128.

Teasdale, R., K. van der Hoeven Kraft, and M. P. Poland (2015). "Using near-real-time monitoring data from Puʻu ʻŌʻō vent at Kīlauea Volcano for training and educational purposes". *Journal of Applied Volcanology* 4(1). DOI: 10.1186/s13617-015-0026-x.

vHub (2022). *Resources: Educational Materials*. gHub. URL: https://theghub.org/resources/educationalmaterials (visited on 11/16/2022).

Wadsworth, F., H. Unwin, J. Vasseur, B. Kennedy, J. Holzmueller, B. Scheu, T. Witcher, J. Adolf, F. Cáceres, A. Casas, V. Cigala, A. Clement, M. Colombier, S. Cronin, M. Cronin, D. Dingwell, L. Guimarães, L. Höltgen, U. Kueppers, G. Seropian, S. Stern, A. Teissier, C. Vossen, and N. Weichselgartner (2018). "Trashcano: Developing a quantitative teaching tool to understand ballistics accelerated by explosive volcanic eruptions". *Volcanica* 1 (2), pages 107–126. DOI: 10.30909/vol.01.02.107126.

Watson, A., B. M. Kennedy, A. Jolley, J. Davidson, and E. Brogt (2022). "Design, implementation, and insights from a volcanology Virtual Field Trip to Iceland". *Volcanica* 5(2), pages 451–467. DOI: 10.30909/vol.05.02.451467.

Wiggins, G. and J. McTighe (2005). *Understanding by Design*. Expanded 2nd edition. Merrill Education/ASCD College Textbook Series, ASCD, Alexandria, Virginia. Expanded. ISBN: 1-4166-0035-3.

APPENDIX A: VOLCANOLOGY HIGHER EDUCATION LITERATURE

[26 (record number)] Teasdale, R., van der Hoeven Kraft, K., and Poland, M. P. "Using near-real-time monitoring data from Puʻu ʻŌʻō vent at Kīlauea Volcano for training and educational purposes". *Journal of Applied Volcanology* 4(1). ISSN: 2191-5040. DOI: 10.1186/s13617-015-0026-x.

[100] Schimmrich, S. H. and Gore, P. J. W. "Exploring Geology on the World-Wide Web – Volcanoes and Volcanism". *Journal of Geoscience Education* 44(4), pages 448–451. ISSN: 2158-1428. DOI: 10.5408/1089-9995-44.4.448.

[119] Kelley, D. F., Uzunlar, N., Lisenbee, A., Beate, B., and Turner, H. E. "A Capstone Course in Ecuador: The Andes/Galápagos Volcanology Field Camp Program". *Journal of Geoscience Education* 65(3), pages 250–262. ISSN: 2158-1428. DOI: 10.5408/15-131r2.

[176] Nunn, J. A. and Braud, J. "A Service-Learning Project on Volcanoes to Promote Critical Thinking and the Earth Science Literacy Initiative". *Journal of Geoscience Education* 61(1), pages 28–36. ISSN: 2158-1428. DOI: 10.5408/11-271.1.

[178] Barclay, E. J., Renshaw, C. E., Taylor, H. A., and Bilge, A. R. "Improving Decision Making Skill Using an Online Volcanic Crisis Simulation: Impact of Data Presentation Format". *Journal of Geoscience Education* 59(2), pages 85–92. ISSN: 2158-1428. DOI: 10.5408/1.3543933.

[209] Parham Jr, T. L. "The InVEST volcanic concept survey: Assessment of conceptual knowledge about volcanoes among undergraduates in entry-level geoscience courses". Iowa State University.

[274] Bhatia, D. and Corgan, J. X. "Using Geodynamics Data Base in a Volcanology Course". *Journal of Geoscience Education* 44(2), pages 161–163. ISSN: 2158-1428. DOI: 10.5408/1089-9995-44.2.161.

[349] Williams, D. A., Fagents, S. A., Greeley, R., and McHone, J. F. "Field exercises in the Pinacate volcanic field, Mexico: An analog for planetary volcanism". *Analogs for Planetary Exploration*. Edited by W. B. Garry and J. E. Bleacher. Geological Society of America. DOI: 10.1130/2011.2483(27).

[385] Hodder, A. "A Titration Technique for Demonstrating a Magma Replenishment Model". *Journal of Geological Education* 31(3), pages 193–197. ISSN: 0022-1368. DOI: 10.5408/0022-1368-31.3.193.

[388] Palmer, R. E. "Learning geomorphology using aerial photography in a web-facilitated class". *Review of International Geographical Education Online* 3(2), pages 118–137.

[389] Boundy, T. M. and Condit, C. "Bringing the Field into the Classroom by Using Dynamic Digital Maps to Engage Undergraduate Students in Petrology Research". *Journal of Geoscience Education* 52(4), pages 313–319. ISSN: 2158-1428. DOI: 10.5408/1089-9995-52.4.313.

[434] Abolins, M. J. "Using Free Digital Data to Introduce Volcanic Hazards". *Journal of Geoscience Education* 45(3), pages 211–215. ISSN: 2158-1428. DOI: 10.5408/1089-9995-45.3.211.

[445] Farver, J. R. and Brabander, D. J. "Magma Ascent Rates from Mineral Reaction Rims and Extension to Teaching About Volcanic Hazards". *Journal of Geoscience Education* 49(2), pages 140–145. ISSN: 2158-1428. DOI: 10.5408/1089-9995-49.2.140.

[576] Parham, T. L., Cervato, C., Gallus Jr, W. A., Larsen, M., Hobbs, J. M., and Greenbowe, T. "Does Students' Source of Knowledge Affect Their Understanding of Volcanic Systems?" *Journal of College Science Teaching* 41(1), page 14.

[713] Boudreaux, H., Bible, P., Cruz-Neira, C., Parham, T., Cervato, C., Gallus, W., and Stelling, P. "V-Volcano: Addressing Students' Misconceptions in Earth Sciences Learning through Virtual Reality Simulations". *Advances in Visual Computing*. Edited by G. Bebis, R. Boyle, B. Parvin, D. Koracin, Y. Kuno, J. Wang, J.-X. Wang, J. Wang, R. Pajarola, P. Lindstrom, A. Hinkenjann, M. L. Encarnação, C. T. Silva, and D. Coming. Springer Berlin Heidelberg, pages 1009–1018. DOI: 10.1007/978-3-642-10331-5_94.

[754] Turney, C., Robinson, D., Lee, M., and Soutar, A. "Bringing the mountain to the student: developing a fully integrated online volcano module". *Planet* 12(1), pages 12–16. ISSN: 1758-3608. DOI: 10.11120/plan.2004.00120012.
[1063] Dohaney, J., Brogt, E., Kennedy, B., Wilson, T. M., and Lindsay, J. M. "Training in crisis communication and volcanic eruption forecasting: design and evaluation of an authentic role-play simulation". *Journal of Applied Volcanology* 4(1). ISSN: 2191-5040. DOI: 10.1186/s13617-015-0030-1.
[1088] Harpp, K. S., Koleszar, A. M., and Geist, D. J. "Volcanoes in the Classroom: A Simulation of an Eruption Column". *Journal of Geoscience Education* 53(2), pages 173–175. ISSN: 2158-1428. DOI: 10.5408/1089-9995-53.2.173.
[1171] Lang, N. P., Lang, K. T., and Camodeca, B. M. "A geology-focused virtual field trip to Tenerife, Spain". *Google Earth and Virtual Visualizations in Geoscience Education and Research*. Edited by S. J. Whitmeyer, J. E. Bailey, D. G. De Paor, and T. Ornduff. 492. Geological Society of America, pages 323–334. DOI: 10.1130/2012.2492(23). [Geological Society of America Special Papers].
[1223] Wadsworth, F., Unwin, H., Vasseur, J., Kennedy, B., Holzmueller, J., Scheu, B., Witcher, T., Adolf, J., Cáceres, F., Casas, A., Cigala, V., Clement, A., Colombier, M., Cronin, S., Cronin, M., Dingwell, D., Guimarães, L., Höltgen, L., Kueppers, U., Seropian, G., Stern, S., Teissier, A., Vossen, C., and Weichselgartner, N. "Trashcano: Developing a quantitative teaching tool to understand ballistics accelerated by explosive volcanic eruptions". *Volcanica* 1 [2], pages 107–126. ISSN: 2610-3540. DOI: 10.30909/vol.01.02.107126.
[1274] Santamarta, J., Tomas, R., Hernandez-Gutierrez, L., Ioras, F., Cano, M., Garcia-Barba, J., Rodriguez-Martin, J., and Neris, J. "Innovative teaching methods and strate-gies in civil, hydrology and geological en-gineering in volcanic subjects". *Proceedings of the 2013 International Conference on Information, Business and Education Technology (ICIBET-2013)*. DOI: 10.2991/icibet.2013.225.
[1298] Mattox, S. R. "An Exercise in Forecasting the Next Mauna Loa Eruption". *Journal of Geoscience Education* 47(3), pages 255–260. ISSN: 2158-1428. DOI: 10.5408/1089-9995-47.3.255.
[1375] Harpp, K. S. and Sweeney, W. J. "Simulating a Volcanic Crisis in the Classroom". *Journal of Geoscience Education* 50(4), pages 410–418. ISSN: 2158-1428. DOI: 10.5408/1089-9995-50.4.410.
[1381] Rowland, S. K., Mouginis-Mark, P. J., and Fagents, S. A. "NASA volcanology field workshops on Hawai'i: Part 1. Description and history". *Analogs for Planetary Exploration*. Edited by W. B. Garry and J. E. Bleacher. 483. Geological Society of America, pages 401–434. DOI: 10.1130/2011.2483(25). [Geological Society of America Special Papers].
[1443] Bursik, M. I., Hodge, D. S., and Sheridan, M. F. "Interactive Computer Modeling of Social and Scientific Issues Related to Volcanic Hazards". *Journal of Geological Education* 42(5), pages 467–473. ISSN: 0022-1368. DOI: 10.5408/0022-1368-42.5.467.
[1554] Gonzales, D. and Semken, S. "A comparative study of field inquiry in an undergraduate petrology course". *Field Geology Education: Historical Perspectives and Modern Approaches*. 461. Geological Society of America, pages 205–221. DOI: 10.1130/2009.2461(18). [Geological Society of America Special Papers].
[1631] Gonzales, D. and Semken, S. "Integrating Undergraduate Education and Scientific Discovery Through Field Research in Igneous Petrology". *Journal of Geoscience Education* 54(2), pages 133–142. ISSN: 2158-1428. DOI: 10.5408/1089-9995-54.2.133.
[1657] Chesner, C. A. and Rose, W. I. "A Videotape Short Course on Volcanic Rock Textures". *Journal of Geological Education* 35(3), pages 134–135. ISSN: 0022-1368. DOI: 10.5408/0022-1368-35.3.134.
[1747] Fitzgerald, R. H., Dohaney, J., Hill, D., Wilson, T. M., Kennedy, B., and Lindsay, J. "Teaching volcanic hazard management and emergency management concepts through role-play: the science behind the Auckland Volcanic Field Simulation". *GNS Science report* 2014(70).
[1792] Parham, T. L., Cervato, C., Gallus, W. A., Larsen, M., Hobbs, J., Stelling, P., Greenbowe, T., Gupta, T., Knox, J. A., and Gill, T. E. "The InVEST Volcanic Concept Survey: Exploring Student Understanding About Volcanoes". *Journal of Geoscience Education* 58(3), pages 177–187. ISSN: 2158-1428. DOI: 10.5408/1.3544298.
[1825] Whittecar, G. R. "A Modified Jigsaw-Type Exercise for Studying Volcanic Landforms". *Journal of Geoscience Education* 48(5), pages 578–578. ISSN: 2158-1428. DOI: 10.5408/1089-9995-48.5.578b.
[1947] Hariyono, E., Liliasari, Tjasyono, B., and Rosdiana, D. "VLP Simulation: An Interactive Simple Virtual Model to Encourage Geoscience Skill about Volcano". *Journal of Physics: Conference Series* 895, page 012142. ISSN: 1742-6596. DOI: 10.1088/1742-6596/895/1/012142.
[2065] Stephens, A. L., Pallant, A., and McIntyre, C. "Telepresence-enabled remote fieldwork: undergraduate research in the deep sea". *International Journal of Science Education* 38(13), pages 2096–2113. ISSN: 1464-5289. DOI: 10.1080/09500693.2016.1228128.
[2082] Johnson, J. and Ruiz, M. "Field Geophysics Class at Volcán Tungurahua, Ecuador". *Eos, Transactions American Geophysical Union* 90(47), page 442. ISSN: 0096-3941. DOI: 10.1029/2009eo470002.
[2179] Lary, B. E. and Krockover, G. H. "Maps, Plates, and Mount Saint Helens". *The Science Teacher* 54(5), pages 59–61.
[2193] Bladh, K. L. "Teaching Hazard-Mitigation Education In a Liberal-Arts College". *Journal of Geological Education* 38(4), pages 339–342. ISSN: 0022-1368. DOI: 10.5408/0022-1368-38.4.339.
[2232] Edwards, B., Teasdale, R., and Myers, J. D. "Active Learning Strategies for Constructing Knowledge of Viscosity Controls on Lava Flow Emplacement, Textures and Volcanic Hazards". *Journal of Geoscience Education* 54(5), pages 603–609. ISSN: 2158-1428. DOI: 10.5408/1089-9995-54.5.603.
[2344] Greeley, R. "The "Holey Tour" planetary geology field trip, Arizona". *Analogs for Planetary Exploration*. Edited by W. B. Garry and J. E. Bleacher. Volume 483. Geological Society of America, pages 377–391. DOI: 10.1130/2011.2483(23). [Geological Society of America Special Papers].

[2363] Lewis, G. and Hampton, S. "Visualizing volcanic processes in SketchUp: An integrated geo-education tool". *Computers & Geosciences* 81, pages 93–100. ISSN: 0098-3004. DOI: 10.1016/j.cageo.2015.05.003.
[2497] Hodge, D., Bursik, M., and Barclay, D. "Simulation of Physical Processes in Environmental Geology Laboratories". *Journal of Geological Education* 43(5), pages 453–460. ISSN: 0022-1368. DOI: 10.5408/0022-1368-43.5.453.
[2498] Hodder, A. P. W. "Using a Decision-Assessment Matrix in Volcanic-Hazard Management". *Journal of Geoscience Education* 47(4), pages 350–356. ISSN: 2158-1428. DOI: 10.5408/1089-9995-47.4.350.
[2499] Tibaldi, A., Bonali, F. L., Vitello, F., Delage, E., Nomikou, P., Antoniou, V., Becciani, U., de Vries, B. V. W., Krokos, M., and Whitworth, M. "Real world–based immersive Virtual Reality for research, teaching and communication in volcanology". *Bulletin of Volcanology* 82(5). ISSN: 1432-0819. DOI: 10.1007/s00445-020-01376-6.
[2503] Renshaw, C. E. and Taylor, H. A. "The educational effectiveness of computer-based instruction". *Computers &amp Geosciences* 26(6), pages 677–682. DOI: 10.1016/s0098-3004(99)00103-x.
[2504] Connor, C. and Vacher, H. "Learning volcanology: Modules to facilitate problem solving by undergraduate volcanology students". *Statistics in Volcanology* 2, pages 1–13. ISSN: 2163-338X. DOI: 10.5038/2163-338x.2.3.
[2505] Dohaney, J., Brogt, E., Wilson, T. M., and Kennedy, B. "Using Role-Play to Improve Students' Confidence and Perceptions of Communication in a Simulated Volcanic Crisis". *Observing the Volcano World*, pages 691–714. ISSN: 2364-3285. DOI: 10.1007/11157_2016_50.
[2506] Teasdale, R., Selkin, P., and Goodell, L. "Evaluation of student learning, self-efficacy, and perception of the value of geologic monitoring from Living on the Edge, an InTeGrate curriculum module". *Journal of Geoscience Education* 66(3), pages 186–204. ISSN: 2158-1428. DOI: 10.1080/10899995.2018.1481354.
[2507] Courtland, L., Connor, C., Connor, L., and Bonadonna, C. "Introducing Geoscience Students to Numerical Modeling of Volcanic Hazards: The example of Tephra2 on VHub.org". *Numeracy* 5(2). ISSN: 1936-4660. DOI: 10.5038/1936-4660.5.2.6.