RESEARCH ARTICLE VOLCANICA

Teaching about volcanoes: Practices, perceptions and implications for professional development

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Abstract

Volcanology education is important for the development of geoscientists and scientifically literate citizens. We surveyed 55 volcanology instructors to determine their learning and teaching practices, perceptions of academic development, and educational support needs. Respondents reported using a wide range of practices and tools, but lectures, field experiences, maps, rock samples, academic literature, and inherited teaching materials are the most common. Respondents valued educational support from others (e.g. talking with colleagues and students, consulting with learning and teaching specialists) over conducting their own investigations. However, they did not report engaging in as many of these activities as they valued. Respondents requested more support in resource sharing and collation, conference workshops, and co-creation of resources and educational research. We suggest that instructors and academic development staff work together to share and build knowledge in the learning and teaching of volcanology in higher education and to improve student learning outcomes.

Non-technical summary

The study of volcanoes is important because students grapple with fundamental questions about science and its impacts on Earth and society. We surveyed 55 people who teach about volcanoes in higher education about the way they teach, how they develop, refine, and access support for their teaching. Respondents commonly taught in lectures and the outdoors, used maps and rock samples, and academic papers and teaching materials inherited from previous instructors. Enhancing and developing their learning and teaching was highly valued by respondents, but they did not report engaging in many of the professional development activities that they valued. Respondents wanted more access to teaching resources, workshops aimed to develop their teaching, and they wanted to embark on collaborations with education specialists. Ultimately, greater development of and engagement with these instructor needs will help to improve how and what students learn about volcanoes and their relationships with humans and the Earth system.

Keywords: Higher education; Educational development; Undergraduate; Postgraduate; Early career researcher;

1 Introduction

Effective teaching is central to any discipline's long-term success by recruiting and retaining bright and diverse individuals and producing passionate graduates with strong scientific knowledge, field skills, and transferable skills, such as critical thinking, teamwork, and communication. Students may be interested in studying volcanology because of prior first-hand experience with volcanoes, or engagement with volcanoes in a variety of informal settings [Connor and Vacher 2016]. Thus, students bring many possible sources of prior knowledge to the higher education classroom [Parham et al. 2011]. This presents volcanology instructors with complex instructional challenges in ensuring consistent student outcomes for varied student backgrounds and interests.

This work represents the first effort, as far as we are aware, to characterise the learning and teaching patterns, interests and support needs of volcanologists, with a view towards a wider picture of academic development in the discipline. Where are we now, and what opportunities might the future hold?

1.1 Definitions

In this section, we draw attention to and define several terms that will be used consistently throughout this work. Much of the terminology in higher education varies globally and may be unfamiliar to readers who have different backgrounds in learning and teaching in

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higher education. Firstly, we use the term 'learning and teaching' to refer to all activities aimed at educating undergraduate and postgraduate students about volcanology. There has been a conscious effort in many educational circles to flip the typical 'teaching and learning' moniker on its head, thereby leading with the students at the centre of the educational experience, rather than the teacher [e.g. Barr and Tagg 1995; Lujan and DiCarlo 2006]. Learning is then positioned as the most important and ultimate goal of these activities. Learning and teaching are thus tightly connected as part of the broader educational ecosystem [Emery et al. 2019].

Throughout this work, we refer to the ways in which people engage with all facets of learning and teaching as 'teaching practices' more generally. 'Practices' are simply the ways in which something is done, and in this case the 'community of practice' [Wenger 1998] being investigated is those who teach about volcanoes. We explicitly consider modes of teaching, the ways in which resources inform teaching, and how support to develop and refine teaching is valued and accessed. Wenger [1998] suggests that a community of practice can only be successful if it documents and builds off of existing practices. This work is not an exhaustive depiction of the landscape of practice [Wenger-Trayner et al. 2014], nor does it capture beliefs about research-based teaching practices. It instead provides a starting point for understanding foundational aspects of how people teach about volcanoes, and thus taking the first steps to document this community of practice.

We use the term 'academic development' to describe work that supports the development of teaching in higher education, by applying evidence-based practices that strengthen student learning [Mårtensson 2014]. Furthermore, this work strives to build functional learning and teaching communities rather than solitary individuals [Felten et al. 2007]. The academic development discipline, synonymous with 'educational development' and 'faculty development', builds and connects professional expertise from many different fields, including psychology, education, sociology, organisational and change management and applied linguistics [Leibowitz 2014]. The work also includes the generation of conditions that support productive learning and teaching cultures [Leibowitz 2014].

Lastly, we use the term 'instructor' to generally describe people who teach in higher education and form the sample for our study. This includes people of all ranks, including but not limited to: lecturers, postdoctoral researchers, professors, tutors, and teaching assistants. We recognise that there are many global variabilities in the terminology used to describe academics and specifically, those who teach. We also acknowledge that the terminology used may have differing implications for experience and rank, depending on the country and institution within which a person may be teaching. We have elected to use 'instructor' because it is all-encompassing and avoids implicitly preferring a particular type of staff member. Academic development supports learning and teaching in all of its forms, including staff in contract or teaching assistant roles and technicians who support teaching and learning.

1.2 Research questions

We set out to capture the state of learning and teaching in volcanology, as described by volcanology instructors themselves. To investigate this, we were driven by the following research questions:

- What teaching modes and tools do volcanology instructors use in higher education?
- What resources do volcanology instructors use to support learning and teaching?
- How do volcanology instructors develop their learning and teaching, and how could this better be supported?

It is important to note that this research was conducted prior to the onset of the COVID-19 pandemic, and thus represents a baseline of practices and perceptions on which the volcanology community may build. In addition, the research survey was written in English and only explicitly mentioned teaching resources written in English.

2 Research context

To contextualise the work herein, we offer a picture of learning and teaching practices and academic development in Science, Technology, Engineering, and Mathematics (STEM) more broadly, as well as within geoscience and volcanology.

2.1 Discipline-general academic development

For full-time academic staff, teaching typically accounts for somewhere between 40 and 100 % of the annual workload. For teaching assistants, this may be less. Regardless, facilitating student learning is a vital part of what we as individuals do, and how we serve society by developing the next generation of volcanologists, geoscientists, and scientifically literate citizens. However, we receive varying degrees of training in learning and teaching and may even be afraid to admit that we are interested in teaching whilst pursuing postgraduate research [Connolly 2010]. Furthermore, research suggests that postgraduate students receive conflicting messages from supervisors about the relationship between research and teaching, both synergistic and antagonistic [Reid and Gardner 2020]. In their work on the research-teaching nexus, Visser-Wijnveen et al. [2010] found that academics who saw

their teacher role as that of a guide tended to focus on training researchers and facilitating experience, whereas those who saw their teacher role as that of an expert tended to focus on teaching research results for building academic knowledge. Differing perceptions of the research-teaching nexus, mixed messages for postgraduate students, and varying training may leave some instructors struggling through teaching, left to emulate the practices that they preferred and/or experienced as students [Oleson and Hora 2013; Cox 2014].

The following are some perceived challenges with academic development and measures of teaching quality that have been reported in the literature:

- There is an over-reliance on student evaluations of teaching as metrics for teaching performance, and these have been shown to be deeply flawed and discriminatory [e.g. Merritt 2008; MacNell et al. 2015; Mitchell and Martin 2018; Peterson et al. 2019]. More appropriate measures of teaching quality are not widely used [Wieman 2014].
- In many institutions, promotion metrics do not emphasise or recognise quality and innovation in learning and teaching [e.g. Brownell and Tanner 2012; Wieman and Gilbert 2015].
- The small percentage of students that go on to be academics are not demographically representative of the wider student population [e.g. Holmes et al. 2008; Bernard and Cooperdock 2018]. Furthermore, higher education instructors are frequently emerging and established researchers, who have developed skill sets and knowledge that are in some ways different from, and even incompatible with, evidence-based learning and teaching [Aragón et al. 2018]. Experts in a field may also suffer from "expert blindness", a concept that describes one's inability to recognise individual steps of problem solving because they have become so automatic as expertise is developed [Wieman 2012, p. 29]. This may result in an inaccurate perception of what learners need and how they should be expected to perform.
- There is a longstanding recognition that the pedagogies of the past are not the most effective for student learning and with it an ongoing push towards more active and student-centred pedagogies [e.g. Hestenes 1979; Hake 1998; Handelsman et al. 2004; Dancy and Henderson 2010; Lombardi et al. 2021]. Higher education reform continues to be influenced by rapid technological change and shifts in workforce needs [e.g. Tierney and Lanford 2016; Hasanefendic et al. 2017], further deepening the divide between some of the pedagogies that instructors experienced as students and what the evidence suggests is most effective for learning.
- It is challenging to offer academic development that takes into account disciplinary differences and practices, whilst still being accessible for all. This is one reason that academic development has seen a general shift towards more context-specific training and connections [e.g. Gibbs 2013; Bush et al. 2016; Chasteen and Code 2018; Sharif et al. 2019].

Academic development, in part, exists to support instructors in their learning and teaching practice, bridging some of these gaps in knowledge and training [Leibowitz 2014]. Many institutions have centres for learning and teaching or similar units staffed with various academic development experts who connect instructors to the knowledge of effective learning and teaching practices, using a mixture of one-on-one and group teaching development, both informally and formally [e.g. Sugrue et al. 2017; Carlisle and Weaver 2018; Sweet et al. 2018; Sharif et al. 2019]. These experts, as well as others within disciplines who have experience with learning and teaching practice and research, also deliver multi-institutional professional development and advance scholarship on an international scale [e.g. Geertsema 2016; Manduca 2017; Carlisle and Weaver 2018]. Through all forms of academic development, the aim is to increase awareness, proficiency with, and uptake of evidence-based practices in learning in teaching, i.e. approaches that we know are successful, much of which comes from vast educational research across many disciplines [e.g. Leibowitz 2014; Geertsema 2016; Knapper 2016; Carlisle and Weaver 2018].

2.2 What do we know about how people teach and access academic support in STEM?

There has been widespread interest in the uptake of evidence-based practices in STEM, particularly in the last couple of decades. However, few institutions collect any data on the types of teaching practices used [Wieman 2014]. This is despite evidence indicating that self-reported instructor practices are consistent with observational data of their classes [e.g. Smith et al. 2014; Wieman 2014] and the wide range of instruments that are available for measuring teaching practices [Williams et al. 2015]. Research investigations into teaching practices suggest that there is a spectrum of use of evidence-based practices, meaning that instructors do not fit simply into either traditional lecturing or fully interactive styles [Smith et al. 2014]. Work has also shown that instructors who use evidence-based teaching methods are less likely to say that barriers to student learning are a result of deficiencies in the students themselves, such as poor preparation or work ethic [Wieman and Welsh 2016].

Some of the more recent literature in STEM academic development has focused on how change is achieved and the application of change management theories to higher education [e.g. Henderson et al. 2010; Borrego and Henderson 2014]. Based on a review of STEM ed-

ucation literature, Henderson et al. [2010] categorised strategies for change under four major descriptors: disseminating curriculum and pedagogy, developing reflective teachers, developing policy, and developing a shared vision (common goals). These categories articulate the breadth of considerations that are needed to accomplish effective academic development and implementation of evidence-based practices.

Emery et al. [2019, p. 469] conceptualised academic development as part of a "complex learning ecosystem" of STEM higher education. They describe departments as "microclimates" [Emery et al. 2019, p. 470] with differing disciplinary cultures, learning and teaching norms, and student bodies. Enacting change through academic development in these microclimates requires attention to the individual, subject-specific, and departmental values and pathways of knowledge transfer through communities of practice [e.g. Wenger 1998; Emery et al. 2019]. Thus, an awareness of the disciplinary context amongst all of this is paramount.

Research suggests that the implementation of evidence-based practices is effective when targeted at the departmental level, within university structures. Departments have a significant influence on what and how disciplinary subjects are taught [Wieman and Gilbert 2015]. They also have the power to help shape professional identities through their sociocultural norms and values [Wenger-Trayner et al. 2014] and create space for the importance of learning and teaching in individual identities [Brownell and Tanner 2012]. This may help reduce the pressure on scientists to choose between research and teaching that has been reported in the literature [Brownell and Tanner 2012]. In turn, this may support a critical mass and advocacy within the disciplinary level, the lack of which has been identified as a potential barrier to pedagogical change [Brownell and Tanner 2012]. Brownell and Tanner [2012] argue that the best ways to create professional identities that are more inclusive of teaching are to incorporate them into doctoral and postdoctoral training, scientific journals, and at professional meetings.

2.3 What do we know about how people teach and access academic support in geoscience?

Awareness of the learning and teaching landscape in the geosciences is an essential foundation for investigating links to academic development. Work on evidence-based practices in geoscience has shown that faculty whose classrooms have been observed to be 'student-centred' report using a higher frequency and duration of interactive activities, such as think-pair-share, small group discussions, and exercises where students work with data [Teasdale et al. 2017]. These instructors also monitor student progress in the classroom and adjust their teaching in response to that [Teasdale et al. 2017]. Another investigation into geoscience teaching practices at varied institutions across the USA showed a wide range of adopted practices, with some faculty moving towards more student-centred and active practice [Budd et al. 2013]. At a single research institution, Markley et al. [2009] found that although most faculty perceived that student learning was strengthened by active engagement, many did not use student-centred practices in their classrooms.

Some efforts have been made to document and investigate academic development practices in the geosciences. The On the Cutting Edge program is a large suite of professional development events specifically targeted at geoscience instructors (graduate students, postdoctoral fellows, and faculty [Manduca et al. 2010; Manduca 2017]). From 2002 to 2012, it is estimated to have impacted 20 % of geoscience faculty across the USA [Manduca 2017]. Self-reported survey data indicate that geoscience instructors are moving towards more diverse and evidence-based teaching practices over time [Manduca 2017]. Results also showed that faculty engaged in this professional development program were more likely to use teaching practices that support student engagement, and that the availability of teaching resources and interactions with peers were supportive of teaching changes [Manduca 2017]. A related program, the Interdisciplinary Teaching of Geoscience for a Sustainable Future (InTeGrate), joins faculty in curriculum development and materials testing [Gosselin et al. 2013], largely in the USA.

Other programs and investigations have been aimed specifically at early career geoscientists, for example, the National Association of Geoscience Teachers' Workshop for Early Career Geoscience Faculty [Beane et al. 2020]. Instructors who participated were more likely than those who did not to use evidence-based teaching practices, to feel part of a geoscience community that shares their perspectives on geoscience education, and to feel that community interactions helped enhance their teaching [Beane et al. 2020]. In their study of academic development practices specifically aimed at postgraduate teaching assistants in the geosciences, Teasdale et al. [2019] found that 73.5 % of geoscience departments required some training in learning and teaching. However, only 45 % of geoscience departments require department-specific training. Furthermore, open-ended comments on their survey indicate that some departmental training solely focuses on rules and regulations, rather than evidence-based practices. Teasdale et al. [2019] end this work with a call for more resources and research in postgraduate teaching assistant training, and an awareness of the influence that instructor and departmental beliefs and norms have in academic development for postgraduate students.

Although many aspects of learning and teaching are transferable from one discipline to another, there are nuances that relate to the specific discipline and topic being taught. There are elements of learning and teaching expertise that are specific to the discipline, such

as which concepts students tend to succeed or struggle with in volcanology, which approach is effective at teaching particular content, and what perceptions students tend to have of the discipline and specific subject matter within it. This is referred to as pedagogical content knowledge, or PCK [Gess-Newsome 1999]. PCK is developed through reading discipline-specific education literature, experience and practice teaching, self-reflection, and teaching with or talking to other instructors in the discipline [e.g. Magnusson et al. 1999; Van Driel and Berry 2012]. PCK is one reason why discipline-general training cannot offer a complete picture of academic development in learning and teaching. However, with the multitude of disciplines and sub-disciplines in existence, it is challenging to offer training that caters specifically to each individual context.

2.4 What do we know about how people teach and access academic support in volcanology?

Disciplinary education repositories provide a space where instructors can search for relevant curriculum material, sometimes accompanied by instructions for implementation, evidence of effectiveness and reflections on how they went. Some of these may contain an implicit or explicit reference to PCK, but as many of these repositories are not peer-reviewed, the information provided may vary in effectiveness. Still, they provide an excellent starting point. Rather than reinventing the wheel, instructors may get inspired by, adapt, or use "as-is" the curricular materials that are available. We are familiar with two online repositories in English that are commonly used in volcanology: The Science Education Resource Center at Carleton College (SERC[*]) and VHub (Volcanology online resource funded by the United States National Science Foundation[†]). The International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) has recently developed a new resource of volcanology videos for learning and teaching (eVolcano[‡]), but this was not available at the time this study was conducted. Aside from these resources, instructors may use a variety of other web resources, academic literature and technical reports, textbooks, and materials inherited from previous instructors to help support their teaching.

To our knowledge, there are no published works that specifically address the learning and teaching practices and perceptions of volcanology instructors. A forthcoming systematic literature review offers a picture of the range of teaching practices employed in the discipline but does not address the self-reported practice or perceptions of volcanology instructors, nor their professional development [Dohaney et al. 2021]. We used our own experiences as volcanology instructors and academic developers to ask questions about the types of teaching practices, resources, and development behaviour that volcanologists were engaging in.

[*] https://serc.carleton.edu/index.html
[†] https://vhub.org/
[‡] https://evolcano.iavceivolcano.org/

3 Methods

In this mixed methods study, we utilised a seven-question questionnaire to explore volcanology instructors' learning and teaching practices and beliefs about academic development (Appendix A). We elected to write our own questions specific to the volcanology context, rather than using a pre-existing instrument aimed at higher education instructors more broadly [e.g. Williams et al. 2015]. The bulk of the questionnaire contained multiple response (select all that apply) questions with fixed options, along with an 'other' option where participants could write in responses that we had not anticipated. The questions covered modes of teaching, teaching tools and resources, and learning and teaching support activities and values. One open response question was included in the questionnaire. This question asked participants to describe how they thought education specialists and researchers might best support the learning and teaching needs of the volcanology community.

Thus, our approach was largely quantitative. This choice was guided by our research questions, as we expected that we could anticipate the majority of the teaching approaches, resources, and support activities that volcanology instructors were engaged in. The quantitative methods were also consistent with the context in which we chose to collect the data. Fixed response questionnaires allow for more rapid data collection and analysis than open questions or interviews, and faster surveying techniques are more enticing to potential respondents. The final open response of the questionnaire offered more in-depth, qualitative data. As we were much less certain about what support needs the volcanology community might have, and we wanted to provide more space for individuals to mention their specific contexts and interests, this approach offered the greatest potential to answer that component of our second research question.

The questionnaire was written by the researchers, based on our previous experience as volcanology instructors, education researchers, and academic developers. We reviewed and iterated the questions for clarity and thoroughness, alongside input from experts who did not participate in the study. This helped ensure content and construct validity. The questionnaire was not validated beyond this as it was outside the scope of this exploratory study. To our knowledge, there are no existing instruments aimed to measure perceptions of learning, teaching, and development in volcanology that have been published in the literature.

3.1 Data collection and research setting

We designed this questionnaire for data collection at a large gathering of the world's volcanologists, the 10th Cities on Volcanoes Conference (CoV) in Naples/Napoli, Italy, on 2nd–7th September 2018. The authors had an exhibit booth where paper copies of the questionnaire were available throughout the conference, with chocolates available as incentives for questionnaire completion. Signs were posted at the booth to recruit participants. Participants had to have taught or be actively teaching volcanology at the higher education level to be eligible to participate (Appendix A, Question 1). Thus, we obtained a convenience sample from CoV attendees. In total, there were 38 respondents to the paper questionnaire.

After collating the paper questionnaire, we noticed that our sample had a high representation of postgraduate students and early career researchers, especially those from countries where the authors had worked. This appeared inconsistent with the demographics of the geoscience teaching population, at least in the US. Results from the National Geoscience Faculty Survey indicated that 19.4 % of US geoscience faculty had six years or less of teaching experience in 2016 [Egger et al. 2019], whereas 74 % of our initial sample reported five years or less of teaching experience. Furthermore, the number of responses we received was lower than we had anticipated. To increase the number of respondents and diversify our study population, we decided to translate the questionnaire to an online format and send it out through a commonly used volcanology mailing list.

The online version of the questionnaire was sent out via the Volcano Listserv*, which reaches a larger proportion of the volcanology community. It had the same questions and was formatted in the same way as the paper version. The online questionnaire was distributed on 28th February 2019 and remained open until 31st March 2019. Entry into a random draw for a gift card valued at $20 CAD was offered as an incentive to participants. A further 17 complete responses were obtained from the online questionnaire, bringing the total number of respondents to 55.

3.2 Study population

The questionnaire respondents (paper and digital) were 45 % men and 55 % women. There were no non-binary or gender diverse respondents. Respondents resided in a range of countries, though mostly split between Europe, North America, and Oceania (Table 1). Three respondents came from Asia, and a single respondent came from each of Africa and South America. This demographic distribution may stem from the nationalities of CoV attendees and volcano listserv members, the location of the conference, the fact that the questionnaire was written in English, or some combination of the above. We do not have access to the demographic makeup of CoV attendees or volcano listserv members.

Fifty-five percent of respondents were in faculty roles, 37 % were postgraduate students, and 8 % came from industry or public research positions. Fifty-five percent of the respondents had between 1 and 5 years of teaching experience, 15 % had between 5 and 10 years, 16 % had between 11 and 20 years, and the remainder were split between less than one year of experience and more than twenty. Three-quarters of the respondents were between 20 and 40 years old, with the remaining quarter over 40 years of age. Although this sample may not be reflective of the volcanology teaching population as a whole, we suggest that it offers a perspective of developing academics, of early career researchers and teachers, and thus, those whom a large proportion of professional development is targeted to and accessed by.

3.3 Data analysis

After the conference, paper questionnaires were digitised by transcribing responses into `Microsoft Excel`. Digital questionnaire responses were collected through `Qualtrics`, which were exported and combined with the digitised paper responses. All data were tabulated using `Microsoft Excel`. As the majority of data collected were nominal/categorical or selected from a range of categories provided in a question (e.g. What resources do you use in your teaching? What types of professional development activities do you engage in?), the frequencies for each of these responses were counted. "Other" responses to these questions were analysed using conventional content analysis [e.g. Popping 2015]. One section of the questionnaire asked respondents to rate the value they placed on particular types of professional development, on a scale of 1 to 7. Thus, the data from this section were ordinal, or in a particular order, but where the distance between specific responses cannot be determined. For this section, descriptive statistics were calculated. Lastly, the open-ended question (What do you feel that education researchers and specialists can do to help the volcanology teaching community to improve learning and teaching in higher education?) was analysed for content and themes. Themes were identified through an initial pass content analysis, then the occurrence of each theme was counted. To support trustworthiness in the findings of the open-ended question, representative responses for each theme are shown below in Section 4.2.

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Table 1: Demographic distribution of survey respondents*

		Paper ($n = 38$)	Digital ($n = 17$)	Total ($n = 55$)
Gender identity	Men	20 (53 %)	5 (29 %)	25 (45 %)
	Women	18 (47 %)	12 (71 %)	30 (55 %)
Geographic region†	Africa	1 (3 %)	0 (0 %)	1 (2 %)
	Asia	2 (5 %)	1 (6 %)	3 (5 %)
	Europe	10 (26 %)	3 (18 %)	13 (23 %)
	North America	9 (23 %)	10 (59 %)	19 (34 %)
	Oceania	16 (41 %)	3 (18 %)	19 (34 %)
	South America	1 (3 %)	0 (0 %)	1 (2 %)
Role‡	Academic Staff	21 (44 %)	15 (88 %)	36 (55 %)
	Postgraduate Students	23 (48 %)	1 (6 %)	24 (37 %)
	Industry/Public Research	4 (8 %)	1 (6 %)	5 (8 %)
Teaching experience	<1 year	1 (3 %)	3 (18 %)	4 (7 %)
	1-5 years	27 (71 %)	3 (18 %)	30 (55 %)
	5-10 years	3 (8 %)	5 (29 %)	8 (15 %)
	11-20 years	6 (16 %)	3 (18 %)	9 (16 %)
	20+ years	1 (3 %)	3 (18 %)	4 (7 %)
Age	21-30 years	16 (42 %)	3 (18 %)	19 (35 %)
	31-40 years	14 (37 %)	7 (41 %)	21 (38 %)
	41-50 years	5 (13 %)	3 (18 %)	8 (15 %)
	50+ years	3 (8 %)	4 (24 %)	7 (13 %)

* Percentages rounded to the nearest whole number.
† Some participants listed more than one option for these questions. For geographic region, total $n = 56$.
‡ For role, total $n = 65$

4 Results

4.1 Teaching methods and resources

Most respondents had taught in lectures ($n = 41$), the field ($n = 39$), laboratories ($n = 30$), and tutorials ($n = 36$), and had graded assessments ($n = 36$; Figure 1). The other types of teaching reported ($n = 10$) included postgraduate supervision and practical research components, seminars and workshops, informal teaching and outreach, and simulation-based teaching. Our sample of 55 respondents reported a total of 194 modes of teaching, indicating that they engage in 3.53 modes of teaching on average.

A wide variety of volcanology teaching tools were reported to be used (Figure 2). The most commonly reported tools included maps and cartographic information ($n = 46$), rock samples and thin sections ($n = 41$), videos ($n = 41$), outdoor field experiences ($n = 39$), quantitative or computational exercises ($n = 34$), physical experiments or demonstrations ($n = 33$), storytelling ($n = 26$), and role-play activities ($n = 21$). Less commonly reported tools included oral histories ($n = 17$), virtual field experiences ($n = 13$), virtual experiments or demonstrations ($n = 8$), and video games ($n = 1$). The other teaching tools reported ($n = 3$) comprised seminars/guest speakers and perception studies.

Academic literature ($n = 47$), inherited teaching materials ($n = 41$), textbooks ($n = 39$), and government web resources ($n = 30$) were by far the most common teaching resources used (Figure 3). Technical reports ($n = 20$), social media ($n = 20$), university web resources ($n = 19$), VHub ($n = 17$), academic blogs ($n = 12$), and SERC ($n = 12$) were used by fewer respondents. The other teaching resources used ($n = 7$) included simulation software, other webpages, posters, peer resources, and academic videos.

4.2 Learning and teaching development and support

Respondents were also asked about the types of learning and teaching development they engage in and how much they value these. The vast majority of respondents talked with colleagues about learning and teaching ($n = 41$; Figure 4). Around half of the respondents talked with their students ($n = 29$) and used surveys to assess their own teaching ($n = 31$). Less than half of respondents engaged in professional development workshops ($n = 18$), read educational research ($n = 16$) or blogs ($n = 18$), consulted with education specialists ($n = 12$), researchers ($n = 11$) and educational technology specialists ($n = 6$), or conducted their own scholarship in learning and teaching ($n = 9$).

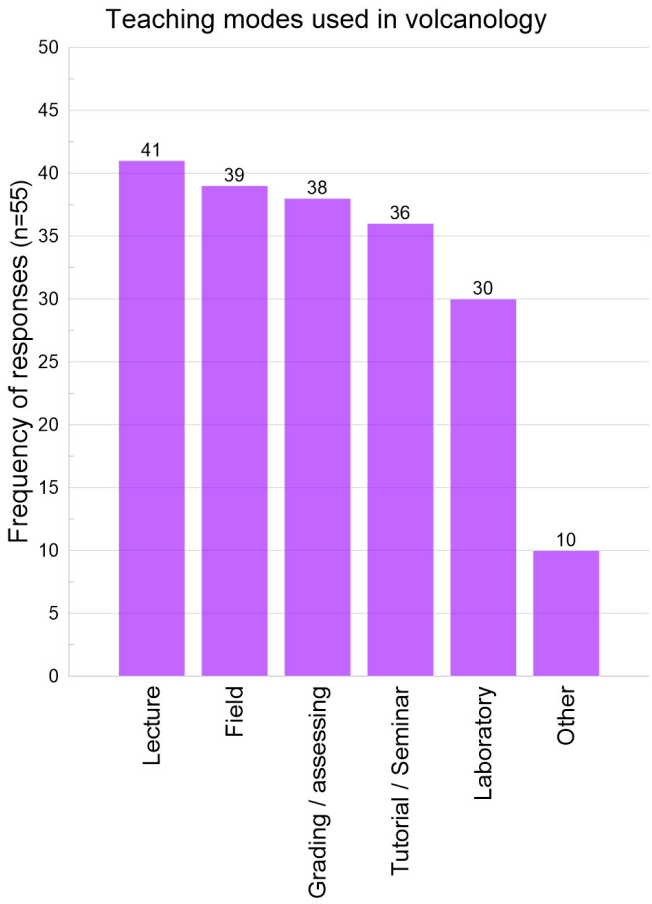

Figure 1: Modes of teaching employed in volcanology instruction by respondents. Note that respondents could select multiple options.

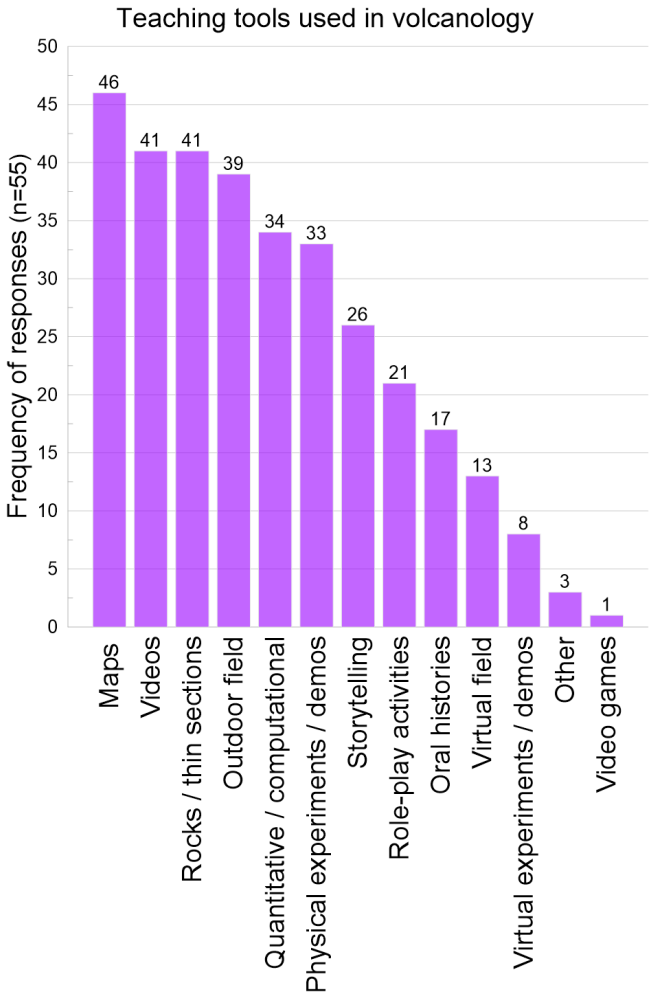

Figure 2: Tools utilised by respondents to teach about volcanic phenomena and their impacts. Note that respondents could select multiple options.

Respondents were also asked what value they would attribute to each of the same activities in supporting their learning and teaching, on a scale of 1 to 7 with 1 being very low value and 7 being very high value (Figure 4). Five activities had a mean rating of greater than 5 out of 7: talking with colleagues, attending professional development workshops, consulting with education specialists on learning and teaching design, consulting with educational technology specialists, and talking with students. The lowest-rated support activities (mean rating lower than 4.33 out of 7) were conducting respondents' own scholarship in learning and teaching, reading learning and teaching research, and reading learning and teaching blogs.

Lastly, respondents were asked an open-ended question about how they felt that education researchers and specialists could best support the volcanology teaching community. Out of 55 respondents, 39 (71 %) completed this question. Through the iterative coding process described in Section 3.3, ten themes were identified, with 60 total mentions (Table 2). The most requested form of support (n = 15) was curating and sharing relevant resources for volcanology learning and teaching, with some respondents indicating that they would like a 'one-stop shop' for these resources. One respondent suggested providing clear scaffolding to the resources: *"Encourage a first 'go-to' resource to start the self-learning, introduce basic concepts and link to more in-depth resources - making it easily accessible so it's clear that hours and hours don't have to be put in"*. The next most requested forms of support were training and exposure to and collaboration on educational research (n = 10 each). Many respondents were interested in taking part in workshops and training sessions run by education specialists for volcanologists. Some specifically suggested running these at conferences.

Respondents were interested in seeing broader educational research shared or in seeing volcanology-specific educational research conducted. Several respondents noted the importance of education specialists making this research accessible to instructors, as exemplified by this response: *"More effective translation of theory into useable guidance"*. Respondents also said that communication and connection between education specialists and volcanologists were important (n = 7). In particular, they noted that education specialists needed to improve the visibility of themselves

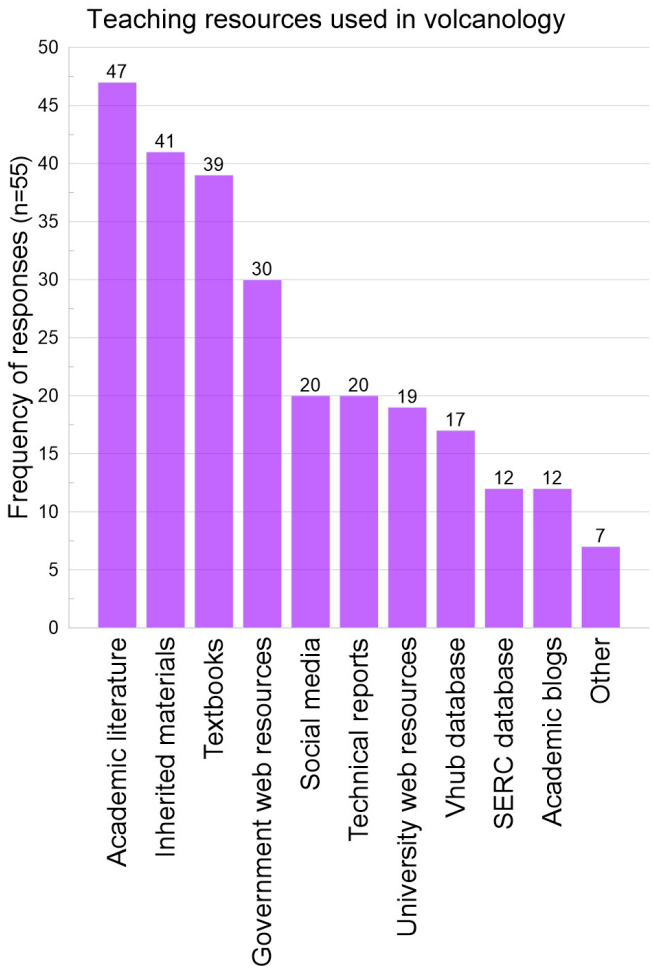

Figure 3: Resources that support respondents' volcanology teaching. Note that respondents could select multiple options.

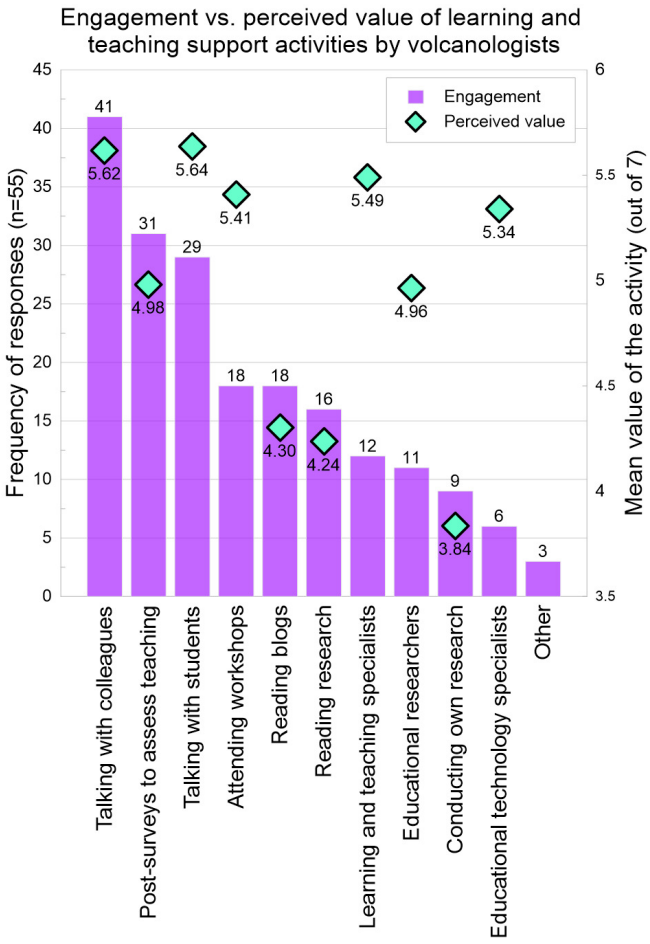

Figure 4: Activities engaged in to support respondents' learning and teaching. The primary y-axis shows the frequency of respondents that said they engaged in each particular activity (instructors could select multiple options). The secondary y-axis shows the mean value respondents placed on each activity, on a scale of 1 being very low value and 7 being very high value.

and relevant resources, along with facilitating connections between people who are interested in volcanology learning and teaching. For example, one participant said: *"I find that I haven't ever really considered going to an education researcher or specialist to improve my learning and teaching, so I think more prominent advertising would be good to raise [instructor] awareness"*. The only specific sub-discipline or types of resources, techniques, and research mentioned were field-based (n = 5) and virtual/accessible (n = 4). For example: *"Create specific resources (online?) for a range of volcanology topics (e.g. mineralogy, etc.) for the specific purpose of education (rather than just information)"*. Respondents are also interested in working together with education specialists to co-develop teaching materials and resources (n = 3). Lastly, respondents suggested having education specialists conduct observations of their teaching (n = 2), connect and communicate more with school teachers and their students (n = 2), and help them to better understand their students' backgrounds and prior training before undertaking volcanology-related classes (n = 2).

5 Discussion

Our findings offer a picture of the approaches and resources used by our respondents in volcanology learning and teaching today and the types of support that respondents utilised and valued. Below, we look across these findings and interpret them pragmatically with a view to the future of volcanology learning and teaching, including the design and provision of professional development. Our interpretations are grounded in prior work that indicates that instructors have many productive views on learning and teaching, even if they are not an exact match to a specific research-based teaching method [Strubbe et al. 2020]. In other words, we believe that academic development should acknowledge and build upon the pre-existing knowledge and agency in the instructional community [Oleson and Hora 2013]. Instructors are partners in the development process, and they are partners who have

Table 2: Representative responses for themes identified in the open-ended responses to how education specialists might help improve volcanology learning and teaching. There were 39 unique responses to this question and 60 total occurrences of themes.

Theme	Description	Frequency ($n = 60$)	Representative response
Share resources	Respondents wanted resources curated for them. Some described a 'one-stop shop' that highlights the basics of learning and teaching alongside additional, more advanced resources.	15	"Provide a one-stop-shop to show us every resource you want us to know about."
Workshops/ training	Respondents were interested in workshops and other training sessions. Some suggested running these at conferences.	10	"Have sessions/workshops during international conferences."
Share and do research	Respondents wanted more exposure to research in (volcanology) learning and teaching, with applications to practice.	10	"Education researchers and specialists can impart best practices to the volcanology teaching community to improve learning and teaching in higher education."
Connection / communication	Respondents described not having much interaction or awareness of education specialists, and wanting connections with them and others interested in volcanology learning and teaching.	7	"Communication. Good connection between teachers and education researchers (academia) is important."
Field	Respondents were interested in resources, techniques, and/or research specific to field learning and teaching.	5	"Research on effectiveness of field teaching methods and techniques to improve accessibility (e.g. virtual field trips, short self-made videos, etc)." (also coded as share and do research and virtual)
Virtual	Respondents wanted resources, techniques, and/or research specific to virtual learning and teaching.	4	"I would love to find more virtual resources so that students who live in a non-volcanic country can experience volcanic environments."(also coded as share resources)
Co-develop resources	Respondents indicated that they wanted to work together with education specialists to develop teaching materials and resources.	3	"Work with teaching community to help develop teaching materials."
Teaching observations	Respondents were interested in having education specialists observe them while they were teaching and provide feedback afterwards.	2	"Watching (real time) the way they [instructors] interact with students."
School links	Respondents wanted more connections and flow of information between academia and the school sector (teachers and students).	2	"Engage earlier. Science field trips for primary aged kids, cultivate from early age."
Student preparedness	Respondents described being unsure of how to assess the level of incoming student knowledge in their classes, and frustration when this does not match their expectations.	2	"I personally have a lot of problems assessing the level of understanding of fundamental physical processes of students before they come into class."

their own views, motivations and decision-making processes that refine their teaching. The practices and perceptions captured below help to serve this purpose by characterising the foundation upon which to build our community of practice [Wenger 1998].

5.1 Teaching methods and resources

Respondents were widely engaged in what has been reported as common modes of higher education instruction in the geosciences and other STEM disciplines, i.e. lectures, laboratories, field education, and tutorials [e.g. Budd et al. 2013; Freeman et al. 2014; Teasdale et al. 2017]. The prevalence of each of these in our dataset indicates that this does not vary by teaching role (e.g. academic staff vs. postgraduate student). Far fewer teach in settings such as seminars, workshops, postgraduate supervision, and informal teaching or outreach (Figure 1). This may speak to the high number of early career academics in our sample and/or to the overall prevalence of more conventional forms of teaching such as lectures and laboratories. It is also possible that some do not immediately think of postgraduate supervision as a form of learning and teaching, as this response was added in by respondents and not included as one of the fixed response options. Regardless, it is clear that academic development in these conventional forms of teaching would serve a wide audience in volcanology. Furthermore, academic development does not need to be targeted at one specific mode of teaching, as most are engaged in a variety. Academic development may be supplemented by training and opportunities in the less commonly reported modes of teaching, such as postgraduate supervision [e.g. McCallin and Nayar 2012; Spiller et al. 2013], particularly in the early career stages.

Many of the commonly used teaching tools reported by respondents (e.g. maps, rock samples/thin sections, physical experiments, and demonstrations; Figure 2) are consistent with what has been described in the wider geoscience education literature and volcanology specifically [e.g. Harpp et al. 2005; Kastens et al. 2009; Mogk and Goodwin 2012; Wadsworth et al. 2018]. The prevalence of storytelling may stem from the narrative aspect of geologic and eruptive histories and of human connections to volcanoes and the Earth system. Eruptions make for compelling and motivating stories to draw students into the work and may even provide alternative sources of knowledge through popular media [Parham et al. 2011]. It would be interesting to consider how narratives are integrated within volcanology education and what perspectives these are and are not from (e.g. have they been modified by colonisation?). For example, do narratives centre diverse scientists [e.g. Schinske et al. 2016; Yonas et al. 2020]? Are local and Indigenous perspectives and knowledge considered and embedded appropriately within the course [e.g. Mercer et al. 2009; King and Goff 2010; Wilkinson et al. 2020]? Fewer instructors reported using oral histories in their teaching than those that reported using storytelling (Figure 2). This suggests there is an opportunity to include more voices in volcanology learning and teaching, and this will require a concerted effort to support inclusion.

Instructors described an interest in virtual and accessible teaching tools at the time of collecting these data (Table 2), which was nearly two years prior to the onset of the COVID-19 pandemic. COVID-19 may have propelled what some were already curious about to the forefront, perhaps even advancing practice through disruption, as some authors have suggested [e.g. Fuller et al. 2020; Trombly 2020; Woolliscroft 2020]. The instructional awareness of and proficiency with virtual teaching materials may have shifted since then, though it is difficult to know whether or not these shifts in knowledge and practice will be sustained [e.g. Cutri et al. 2020; Rupnow et al. 2020]. Emerging research suggests that though instructors had negative perceptions of remote field teaching substitutions due to COVID-19, they reported implementing a variety of promising alternatives, though not without concern for heightening inequities in technological access [Barton 2020]. Efforts such as the National Association of Geoscience Teachers (NAGT) workshops to develop online field experiences (NAGT Field*) and the *Geoscience Communication* special issue on virtual geoscience education resources† showcase the work done by geoscience instructors to support online learning. In addition, there is a rich and ever-growing body of research on accessible geoscience education, particularly with respect to field education, that may inform continued development in this area [e.g. Gilley et al. 2015; Carabajal et al. 2017; Hendricks et al. 2017; Stokes et al. 2019; Kingsbury et al. 2020]. Now is the time to share what we have learned and developed on virtual and accessible teaching through COVID-19, adding to the wealth of geoscience curricular innovation that has been borne out of the pandemic.

Field teaching was widely engaged in by respondents; however, it was still mentioned specifically as an area where people would like learning and teaching support (Table 2), securing its importance in volcanology and the geosciences [e.g. Kastens et al. 2009; Stokes and Boyle 2009; Petcovic et al. 2014]. There is a clear need and interest in thinking about learning and teaching in this realm. From an academic development standpoint, this is an opportunity to showcase the field education research that has already been conducted, as well as the potential for new investigations. One way to approach this may be to leverage the interest in field education to discuss learning and teaching more broadly.

Although respondents reported using resources such

*https://serc.carleton.edu/NAGTWorkshops/online_field/index.html

†https://gc.copernicus.org/articles/special_issue431_1145.html

as academic literature, inherited materials, and textbooks (Figure 3), few are utilising online repositories that contain teaching materials developed specifically for geology and volcanology (e.g. SERC, VHub). It is unclear if this is because these resources are not visible or accessible or if they have been explored but found not to be relevant. Responses to the open-ended question about learning and teaching support clearly highlight that many respondents are not aware of these resources (Table 2), so we are inclined to think this is the primary factor. Interest in learning and teaching resources in volcanology and more generally was the most commonly requested form of learning and teaching support in the open-ended question on the questionnaire. Respondents indicated that they valued research and expertise in higher education; however, they placed less value on reading that research themselves. One potential explanation for this is that respondents may not have had the opportunity to build confidence with the scholarship of learning and teaching [e.g. Barnard et al. 2011; Bailey et al. 2021]. Alternatively (or perhaps concurrently), the reluctance to engage with research in higher education may be due to the fact that university systems do not equally incentivise or reward teaching compared to research, nor do they commonly reward research-based teaching [e.g. Brownell and Tanner 2012; Wieman and Gilbert 2015]. Regardless, advocates of volcanology education need to share and curate relevant research and resources to this community, thus supporting the development of pedagogical content knowledge [PCK; Gess-Newsome 1999]. The use of learning and teaching resources has been shown to support shifts to more student-centred teaching practices in the geosciences [Manduca 2017].

5.2 Learning and teaching development and support

Respondents placed a high value on many aspects of learning and teaching. This aligns with academic development literature that shows the agency and productive views in learning and teaching that instructors have [e.g. Oleson and Hora 2013; Strubbe et al. 2020]. The most common practice that respondents engaged in to support their learning and teaching was discussions with colleagues. Work in the geosciences suggests that peer discussions are supportive of changes in teaching practice [Manduca 2017; Beane et al. 2020]. Some respondents talked to students about their teaching. Discussions with colleagues and students are both time and resource minimal activities to engage in. Thus, we should continue to capitalise on these approaches. This also suggests that academic development that enables the formation of teaching networks might be particularly beneficial [e.g. Wenger 1998; Brownell and Tanner 2012; Wenger-Trayner et al. 2014; Wieman and Gilbert 2015; Manduca 2017; Beane et al. 2020]. To support further engagement with student feedback, academic developers could focus on the ways in which instructors might collect and use this information in a meaningful way.

Far fewer respondents engaged in other aspects of learning and teaching support, although they were valued. Attending professional development workshops, consulting with education specialists on learning and teaching design, and consulting with educational technology specialists were the highest valued types of learning and teaching support that were not being widely utilised by respondents. A wide body of professional development literature has addressed the barriers that prevent instructors from engaging in learning and teaching development [e.g. Henderson et al. 2010; Brownell and Tanner 2012]. These barriers include lack of time, lack of recognition for participation in learning and teaching improvement, lack of departmental or institutional support, and perceived lack of availability of educational support and resources [Dohaney et al. 2020]. Thus, it is not surprising that respondents did not currently engage in all the forms of support that they perceived as valuable. However, our results do highlight this gap in what respondents are doing and what they value (Figure 4). Like many other academic communities [e.g. Brownell and Tanner 2012; Emery et al. 2019], we must work hard to address this gap, overcome these barriers, and document the impacts of professional development initiatives. Education specialists can help to provide support and advocate for change, but it is ultimately the responsibility of instructors to engage in evidence-based teaching practices [Wieman 2014].

5.3 Limitations

This exploratory study represents an initial effort to characterise the learning and teaching perceptions of volcanologists. It should be noted that our sample represents a small slice of perspectives ($n = 55$) and is not intended to be generalisable across the population. In addition, our sample likely carries with it some bias. Early career instructors are overrepresented in our sample (based on the US faculty distribution reported in Egger et al. [2019]). However, preliminary analyses did not indicate major differences in the response patterns of individuals with differing levels of teaching experience. Thus, we elected to keep the sample together. In addition, our sample is predominantly comprised of instructors working in English speaking countries. This is not surprising given that the questionnaire was written in English, but it should be noted that interpretations are limited to this population. This questionnaire may also have attracted particular interest from those who are already interested in learning and teaching, simply by its content and the fact that it was offered at a learning and teaching–focused exhibit booth.

Given the scope and timeline of the project and the lack of specialist instruments already in existence, we opted to write our own questionnaire for this study.

The questionnaire has not been psychometrically validated, as this was outside the scope of this study. We developed a straightforward and simplistic questionnaire to minimise the chances of misinterpretation. However, it is still possible that respondents interpreted the items differently than intended. For example, some may have interpreted 'storytelling' to only mean written narratives, even though this was not our intention.

6 Implications for the future of volcanology learning and teaching

To advance volcanology learning and teaching, education specialists can help enhance the visibility and accessibility of existing resources for instructors, translate education literature into practice, and create discipline-specific resources and training, thereby facilitating connections between volcanologists and education specialists. Our findings show that instructors are already engaging in varied teaching practices and accessing some supporting resources. However, many instructors are not utilising repositories of discipline-specific teaching materials (e.g. SERC, VHub), despite the variety and depth of resources available. We encourage instructors to seek out resources for their area and consider that minor changes may be needed to adapt a resource for a specific context. Additionally, volcanology instructors can help to grow these communities even further by submitting their own learning and teaching materials. These repositories often do not require extensive peer review, but there is a submission process that ensures that what is provided contains sufficient information for someone else to utilise the materials in their teaching. Answer keys on SERC are only available to verified instructors.

It is imperative that materials and support are accessible and relevant to the instructors that want to use them. Therefore, existing resources need to be more visible and perhaps curated into one location, as suggested by several respondents. It is important to remember to view this simply as a starting point for looking at learning and teaching. There are plenty of educational materials and resources available and not all will be suitably aligned with desired learning outcomes. However, an initial 'one-stop shop' (as described by a few respondents) can help demystify the teaching and curriculum development process by introducing instructors to broad learning and teaching resources and resources that are specific to volcanology.

We hope that others will consider sharing their volcanology learning and teaching knowledge and experiences through conference workshops, technical sessions, and publications. There is clearly an interest in learning and teaching within the field of volcanology, and these suggestions offer some of the ways in which volcanology instructors may connect and collaborate on learning and teaching.

Instructors indicated that they value collaborations with education specialists, but this was one of the lesser engaged activities reported upon. Education specialists can help with many of the things that people requested including: sharing educational resources and effective practices, classroom observations, support in developing or evaluating curriculum materials and assessments, finding ways to measure incoming student knowledge in classes, and co-conducting scholarship in learning and teaching. Education specialists may also deliver workshops or help identify off-site workshops of interest. Workshops are another activity that instructors placed a high value on but did not report engaging in as frequently.

However, some respondents said they did not know that connecting with education specialists was an option or that education specialists were not visible in their context. Instructors who are affiliated with an academic institution could see if there is a Centre for Learning and Teaching or similar unit on their campus, which is typically staffed with people who support teaching development and educational technology. Some institutions even have STEM-specific centres. Colleagues who are not in support roles, but have expertise in education, might also be interested in collaborating on subject-specific education research*. Lastly, those who have published volcanology education research or led sessions or workshops on volcanology education, including the authors on this paper, may be open to collaboration.

6.1 Future research

It would be worthwhile to repeat or expand upon this study with a larger sample size that spans more varied career levels and backgrounds (e.g. languages other than English) to capture more voices, and thus, a more representative sample. The study could also be built on by considering the perceived skills and knowledge needed by employers in the volcanology workforce and how these relate to the learning and teaching practices being engaged in within higher education settings. In addition, there may be differences in instructor practices and perceptions in the post-COVID context. A follow-up study, and one that specifically addresses shifts in and reflections on learning and teaching practice and support could offer some insight into the nature of these differences. How volcanologists compare to the broader geoscience and STEM populations may also offer insight into the applicability of varying levels of support and development.

As the majority of the questions in our questionnaire were fixed response, there was limited opportunity to understand the reasons why participants responded

*e.g. *Learning for Earth Ako Futures*; https://blogs.canterbury.ac.nz/leaf/

how they did. Future studies may probe these in further detail, e.g. through more open-ended questions or with interviews on similar topics. For informing future academic development, it would be helpful to know why instructors use particular resources and tools and if there are some that they wished they used or want to learn more about. In particular, instructors indicated an interest in field-based, virtual, and accessible volcanology teaching. We suggest considering who has access to the outdoors, centring Indigenous knowledge, and including diverse voices through the exploration of these topics. As noted above, this must be engaged in thoughtfully and appropriately, e.g. by collaborating with partners. It would also be interesting to uncover some of the barriers to engaging in learning and teaching development and whether or not these are similar to other fields. Are there challenges unique to volcanology? Are there approaches or solutions that might work particularly well in our context, or conversely, be less effective?

As we, and others, continue to develop and implement volcanology-specific learning and teaching development based on these findings, it will be essential to evaluate the success of these initiatives. Success may be defined by interest and uptake, shifts in knowledge and evidence-based practices, perceptions of utility, relevance, and self-efficacy, or other metrics. Reflective practice should be a mainstay of this process [e.g. Schön 1983; Brookfield 2017], constantly re-evaluating and understanding if and how instructor needs and interests are shifting. This may be assessed in relation to a forthcoming literature review that characterises published studies in volcanology learning and teaching in higher education [Dohaney et al. 2021].

7 Conclusions

This exploratory study aimed to characterise the practices and perceptions of learning, teaching and educational support within volcanology, with implications for the design and implementation of professional development for volcanologists. We surveyed 55 volcanology instructors using a mostly fixed-response questionnaire, with opportunities to write in practices and resources that were not captured by the response options. We also included an open-ended question asking about volcanology instructors' needs for educational support. Several key findings emerged from our data:

- Respondents commonly taught in lecture, field, laboratory, and tutorial settings. Teaching through postgraduate supervision, seminars, workshops, and outreach was mentioned less.
- Maps, rock samples / thin sections, videos, outdoor field experiences, quantitative or computational exercises, physical experiments or demonstrations, storytelling, and role-playing activities were used by many respondents. Oral histories, virtual field experiences, virtual experiments or demonstrations, and video games were less commonly used.
- Over half of the respondents used academic literature, inherited teaching materials, textbooks, and government web resources in their teaching. Fewer respondents utilised technical reports, social media, and discipline-specific teaching repositories such as VHub and SERC.
- Respondents largely supported and developed their teaching by talking with colleagues, using surveys to assess teaching, and talking with students.
- There was a gap between what learning and teaching support respondents valued and what they engaged in. Although respondents reported a high value of attending workshops, working with learning, teaching, and educational technology specialists, and working with educational researchers, these activities were much less engaged in.
- When asked what education specialists could do to help with learning and teaching, respondents wanted to see more resources and workshops offered. They wanted educational research conducted specifically on volcanology and shared with them. They also described a need for more connection with and communication between education specialists and those interested in volcanology learning and teaching, including co-developing resources. Field, virtual, and accessible education were all identified as areas of interest to respondents and the need for these to be more visible was emphasised.

Instructors have many productive views and practices of learning and teaching and place a high value on many aspects of academic development. Based on this, we suggest the following to better support learning, teaching, and professional development:

- Training and opportunities that leverage commonly used modes of teaching in volcanology, e.g. lecture, field, laboratory, and tutorial settings.
- There are opportunities to incorporate more oral histories and virtual materials (field experiences, experiments, and demonstrations) into volcanology teaching, with an eye to accessibility and inclusion.
- Volcanology instructors would benefit from learning and teaching resources and educational research (in volcanology and more broadly) that are more user-friendly and accessible to practitioners. Instructors would also benefit from engagement with discipline-specific learning and teaching repositories (e.g. VHub, SERC). This includes

adapting and/or using materials and sharing self-created materials.

- Volcanology learning and teaching workshops and conference sessions are of interest to instructors. Respondents were particularly interested in the basics of learning and teaching, teaching in the field, and teaching using virtual and accessible means.
- Instructors should continue to discuss learning and teaching with their colleagues and students. Professional development should be designed with the facilitation of teaching networks in mind. Volcanology instructors could also be supported to further engage with student feedback and assessment of learning outcomes.
- We encourage volcanologists interested in learning and teaching to build their own local and international teaching networks. This could include other instructors, volcanology and other education researchers, and educational support staff focused on teaching development and/or technology.

It is clear from our findings that there is enthusiasm and value for learning, teaching, and academic development within volcanology. Our recommendations offer some ways to carry this forward through reflective practice, resources, professional development, research, and community networks. These pathways offer promise for refined learning and teaching practice, increased instructor self-efficacy, and enhanced student outcomes.

Acknowledgements

Thank you to all of the instructors who completed the questionnaire and shared their experiences of learning and teaching in volcanology. The distribution of the paper questionnaire was aided by volunteers who staffed our booth at Cities on Volcanoes 2018. The distribution of the digital questionnaire was facilitated by the Volcano Listserv. Comments from two reviewers and an editor greatly improved this manuscript. Kennedy would like to acknowledge the ECLIPSE Supervolcano project funded by the MBIE Endeavour Fund NZ. This research was approved by the University of British Columbia Office of Research Ethics (approval #H18-02214). We thank Professor Sara Harris for her assistance in preparing the human ethics application.

Author contributions

Dohaney conceptualised the idea for the study. Jolley, Dohaney and Kennedy developed and refined the survey questions and Jolley submitted the human ethics application. Jolley and Dohaney collected the paper data from Cities on Volcanoes and Jolley collected the digital data. Jolley analysed the data and Jolley, Dohaney and Kennedy interpreted it. Jolley, Dohaney and Kennedy all wrote the manuscript.

Data availability

Raw data are unavailable for this research as this would violate human ethics protocols. We have included comprehensive, anonymised, and aggregated summaries of the data within this manuscript.

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Appendix A
Volcanology Education Questionnaire

Note: Format has been altered from original (removed line spacing).
Instructions
Before you start:

- This questionnaire is intended to examine your perceptions and experiences about learning and teaching volcanology.
- Please complete the questions to the best of your ability.
- It is an anonymous survey, please do not include identifiable information such as your name
- If you have questions about your rights as a participant or are confused by the language in the questionnaire, please ask the researcher for assistance.

Before beginning, please respond to the following statement:
☐ I understand that by completing this questionnaire, I am consenting to participation in the research.

Question 1. Teaching volcanology

Have you taught or are currently teaching volcanology topics within a higher education context?
☐ Yes ☐ No
Teaching volcanology includes:

- Teaching volcanology topics in a lecture-based course
- Teaching volcanology topics in the field
- Teaching volcanology topics in a laboratory course
- Teaching volcanology topics in a tutorial or seminar
- Grading and assessing volcanology assignments for a course

No?

If you have not taught volcanology, please return the survey to the researcher. Thank you for your time!

Yes?

Please flip over the page, and continue the rest of the survey

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Question 2. Teaching mode

What modes of teaching have you taught (past or present)? Select all that apply.
☐ Teaching volcanology topics in a lecture-based course
☐ Teaching volcanology topics in the field
☐ Teaching volcanology topics in a laboratory course
☐ Teaching volcanology topics in a tutorial or seminar
☐ Grading and assessing volcanology assignments for a course
☐ Other? _____

Question 3. Teaching tools

Select the tools that have you used in your volcanology teaching (past or present) about volcanic phenomena and their impacts. Select all that apply.
☐ Rock samples and thin sections
☐ Maps and cartographic information
☐ Outdoor field experiences
☐ Virtual field experiences
☐ Videos
☐ Story telling
☐ Oral histories
☐ Video games
☐ Role-play activities
☐ Physical experiments or demonstrations
☐ Virtual experiments or demonstrations
☐ Quantitative and computational exercises
☐ Other? _____

Question 4. Resources

What resources do you use to support your volcanology teaching? (Select all that apply)
☐ Inherited materials from previous teacher(s)
☐ Textbooks
☐ Academic literature
☐ Government web resources
☐ University web resources
☐ Technical reports
☐ Academic Blogs
☐ Social Media
☐ SERC (Science Education Resource Centre) – Carleton College
☐ VHub (Volcano Resource Website) - National Science Foundation
☐ Other? _____

Question 5. Supportive activities

A. Do you **currently engage in any of the following activities** to support your learning and teaching (L&T) of volcanology topics? (Select all that apply)
☐ Reading L&T research from the academic literature
☐ Reading L&T blogs and other internet-based sources
☐ Talking about L&T with your colleagues
☐ Attending L&T workshops by education specialists
☐ Working with specialists who help you develop your L&T strategies
☐ Working with specialists who help you develop your use of educational technology
☐ Working with educational researchers
☐ Talking with your students about how you are teaching
☐ Using post-teaching surveys to assess your teaching
☐ Conducting your own scholarly research in L&T
☐ Other? _____

B. In an ideal world (with unlimited resources and no time limitations), rate what you feel is the value that you personally would attribute to these activities in supporting your L&T of volcanology topics. Rating of: 1 – Very low value (i.e., not at all valuable to you), to 7 – Very high value (i.e., absolutely essential to you)

Activities	Rating Low High
Reading L&T research from the academic literature	1 2 3 4 5 6 7
Reading L&T blogs and other internet-based sources	1 2 3 4 5 6 7
Talking about L&T with your colleagues	1 2 3 4 5 6 7
Attending L&T workshops by education specialists	1 2 3 4 5 6 7
Working with specialists who help you develop your L&T strategies	1 2 3 4 5 6 7
Working with specialists who help you develop your use of educational technology	1 2 3 4 5 6 7
Working with educational researchers	1 2 3 4 5 6 7
Talking with your students about how you are teaching	1 2 3 4 5 6 7
Using post-teaching surveys to assess your teaching	1 2 3 4 5 6 7
Conducting your own scholarly research in L&T	1 2 3 4 5 6 7

Question 6. How can we help?

What do you feel that education researchers and specialists can do to help the volcanology teaching community improve learning and teaching in higher education? (Open question)

Question 7. Demographics

Please tell us a little about yourself:

Your age: _____

Your gender identity: _____

Your current home, school or work location (where you spend the majority of your time)
Country: _____

The country in which you underwent (or are currently undergoing) highest level of education in volcanology?
Country: _____

Which best describes your current role title?

☐ Undergraduate student Graduate or postgraduate student (Masters, PhD)
☐ Post-doctorate Research Fellow
☐ Senior Research Fellow Lab Technician
☐ Teaching Assistant Tutor or Senior Tutor
☐ Teaching Fellow Senior Teaching Fellow
☐ Associate Lecturer Assistant Lecturer
☐ Privatdozent(in) Professeurs certifiés
☐ Lecturer Senior Lecturer
☐ Reader Assistant professor
☐ Associate professor Docent
☐ Professor Adjunct Professor
☐ Dean Retired
Other: _____

Estimate the total number of years that you have taught volcanology topics?

☐ less than 1 year ☐ 1-5 years ☐ 5-10 years ☐ 11-20 years ☐ more than 20 years

Thank you for your time. If you have any further comments relating to how we teach about volcanology, please contact the researcher.