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Research article

Incorporating science communication and bicultural knowledge in teaching a blended volcanology course

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Abstract. A variety of skills can be taught alongside course content. In the University of Canterbury third-year course on magmatic systems and volcanology, we chose to focus on teaching bicultural competence and science communication, while transforming the course to a more skill-based, flexible, flipped-classroom model. We document the development process and measure student perceptions associated with these skills. We used two edX massive open online courses (MOOCs) on volcanology as skill-focused learning resources to replace lectures and supplement hands-on laboratory and tutorial sessions to teach volcanology.

We compare the skill-focused courses with baseline data from 2021, gathered during an initial iteration of the course that included interactive volcanology lectures and an online Iceland virtual field trip component. The new course was developed using the original 2021 Iceland virtual field trip to create the two virtual-field-trip-based MOOCs with new bicultural and science communication components. To achieve this, we used cultural advisors from connections through Aotearoa / New Zealand research programmes and kaiārahi (Māori learning advisors) from the University of Canterbury. In the course, these experts ensured appropriate cultural guidance at specific volcanic sites and appropriate assessments. Mātauranga (Māori knowledge) of volcanoes is included and taught by video of kōrero (oral knowledge) from members of mana whenua (tribes local to the volcanoes) in the areas that are visited in the course.

In this paper, we describe the development of a flipped-classroom MOOC featuring bicultural competence and science communication skills, and we report students' reflections on learning with a focus on these featured points. We analyse student reflections and comments from the two iterations of the online content by specifically coding for comments regarding skills learnt. Student responses to the reflective question "What did you learn in this course and why is it important to you and/or your potential career?" show a marked shift between the years. In the new 2022 course, students' reflections were more likely to highlight a skill, rather than content, and there was a large increase in the number of students who reported science communication or bicultural competence as a potential skill that would be useful to them. Student quotes from throughout the course and in response to the reflective question "Has this course influenced your bicultural competence?" are used to explore how and why these skills were valued by the students. These courses provide a freely available and potentially flexible model to teach bicultural and science communication skills alongside volcanology.

1 Introduction

Geoscience instructors teach content and skills in a variety of settings, e.g. lectures, laboratories, online modules, projects, and during in-person and virtual-field-trip experiences. To learn and master new skills, students need to employ adaptive expertise techniques (Bohle Carbonell et al., 2016) and distributed practice (Benjamin and Tullis, 2010) by practicing skills multiple times and in different scenarios. Bicul-

tural confidence is a valued skill in Aotearoa / New Zealand[1], and cultural confidence and cultural competence are important globally and inherently linked to sense of place, a key concept in the geosciences (Apple et al., 2014). However, cultural competence is rarely taught in geoscience courses (Mosher and Keane, 2021). Here, we present how we integrated a new skill-based learning goal (including bicultural confidence) into the course. This additional learning goal was introduced and assessed in a third-year volcanology course using two massive online open courses (MOOCs) and a flipped-classroom model. Here, we define flipped classroom, in our context, as a teaching format in which the majority of the content is transferred outside of scheduled class time via an interactive MOOC, and face-to-face time is used following this content to consolidate knowledge and reflect on learning during workshops and labs.

Teaching and learning about volcanoes is of public and professional interest, particularly in countries with significant volcanic risk like Aotearoa / New Zealand (NZ). MOOCs are a method via which (1) public, professional, and institutional audiences can be reached (Rodrigues-Silva and Alsina, 2024) and (2) skills important to become effective volcanologists can be taught. Flipped classrooms provide a scenario in which content is delivered outside of the classroom during a time and at a pace that suits the individual student, whereas "homework" is turned into more active learning that takes place in the classroom (Bergmann and Sams 2012), although the flipped model is variably applied and assessed (Kapur et al., 2022). When flipped classrooms are combined with interactive online material (Wang and Zhu, 2019; Forbes et al., 2023), students can be given opportunities for adaptive expertise and distributed practice using workshops and laboratories, during which feedback and reflection are used to cement the learning of skills. However, both MOOCs and flipped classrooms have challenges: MOOCs have low completion rates and frequently lack meaningful peer and instructor interaction (Khalil and Ebner, 2014; Kurtz et al., 2022), whereas flipped classrooms frequently require very high levels of "buy-in" from both instructors and students (Collopy and Arnold, 2009). Studies in which MOOCs and flipped classrooms are combined have reported some benefits over the stand-alone models (Ghadiri et al., 2013).

The aims of the study are to (1) describe the development of a flipped-classroom MOOC targeting bicultural competence and science communication skills; (2) report students' reflections on learning in 2021 and in 2022, by coding reflections for comments relating to bicultural competence and science communication; and (3) discuss how the students' reflections relate to specific course developments by comparing the findings from the 2021 and 2022 student reflections and focus groups.

[1] Although Aotearoa is a Māori name for New Zealand's North Island, to reflect the nations bicultural foundation, it is commonly and increasingly used in this way, e.g. Aotearoa / New Zealand, or simply Aotearoa NZ, to mean New Zealand.

2 Literature context

2.1 Geoscience skills

Volcanology courses exist as part of a geoscience programme, where course development, such as introducing new skills, is achieved by mapping knowledge, skills, and attitudes across courses to ensure that graduate learning objectives are met that service the geoscience workforce (e.g. Mosher and Keane, 2021). The skills required by geoscience employers are communicated to faculties and professional bodies via research on job advertisements (Shafer et al., 2023), focus groups (Nyarko and Petcovic, 2022), and working groups with academics (Mosher and Keane, 2021). These studies show the skills most valued by employers – specifically, writing, field and data collection, planning, communication, teamwork, and interpersonal skills. Therefore, it is important to consider which of these skills are currently included in the curriculum (Keane et al., 2022; Mosher and Keane, 2021; Viskupic et al., 2021) so that we can identify the skill deficits that need to be taught.

A general survey of the workforce highlighted geoscience skills within geoscience courses of undergraduate geoscience programmes (Viskupic et al., 2021). The survey reported that geoscience skills (e.g. rock description), data skills, and communication skills were commonly practised across many courses, although it should be noted that the communication skills reported were around communicating with peers and the instructor and did not specifically relate to communicating with the public or those outside of geosciences. Complementary to this, a status of geoscience graduates report (Keane et al., 2022) highlighted three areas for improvement amongst our geology graduate students: (1) working across cultures, (2) communicating with the public, and (3) working in interdisciplinary teams. This report, coupled with ongoing curriculum reform at the University of Canterbury, provided the motivation to develop, implement, and research the integration of these skills within an existing third-year volcanology course.

A range of practice-oriented, authentic, and/or work-integrated tasks and assessments have been shown to be effective with respect to developing graduate attributes in education and nursing (Gulikers et al., 2004; Karunanayaka and Naidu, 2021). These tasks range from work placements, field trips, and simulations to practice-oriented or authentic assessments (Kaider et al., 2017). Work placements and field trips have been shown to be effective, authentic experiences aligning with desired skills (Miller and Konstantinou, 2022), but they are also time- and resource-intensive, expensive, and not always equitable experiences (Kaider et al., 2017). Therefore, simulations and virtual field trips have been used and can be particularly affective when coupled with authentic as-

sessment to augment, achieve added value, or provide alternatives (Watson et al., 2023).

2.2 Volcanology learning and teaching research

Recent research into teaching and learning in volcanology has provided evidence of research gaps (Dohaney et al., 2023a, b). Volcanological learning and teaching research at a tertiary level has focused on research skills and and field skills, followed by volcano monitoring, communication, teamwork, and quantitative skills (Dohaney et al., 2023a, b). In addition, a gap in research relating to addressing a lack of diversity is becoming increasingly recognised; hence, addressing this issue is a burgeoning area of research in geosciences (Gates et al., 2019; Mogk, 2021) and volcanology (Dohaney et al., 2023a, b). Communication skills have typically been taught using role-play exercises and simulations (Harpp and Sweeney, 2002; Nunn and Braud, 2013; Barclay et al., 2011; Teasdale et al., 2015, 2018; Dohaney et al., 2015a b, 2017), but they have also been incorporated into lectures and labs (Whittecar, 2000; Gonzales and Semken, 2006).

2.3 Cultural sensitivity in geoscience education

As much of geoscience is landscape and location focused, it is inherently linked to culture (e.g. sense of place; Apple et al., 2014), and cultural considerations can be crucial when working in this field (Mosher and Keane, 2021). Despite this, working across cultures is rarely taught in the geosciences (Mosher and Keane, 2021). Coincidentally, or consequently, diversity is low in geosciences compared with other sciences. Geoscience education needs to be culturally responsive by explicitly centring indigenous students and addressing racism, indigenous identity, sovereignty, and data sovereignty (McKinley et al., 2023). Key strategies for indigenous student success are multi-faceted, layered support, underpinned by the principles of respect, relationships, and responsibility (Milne et al., 2016). Successful Earth science curricula for indigenous learners include outdoor education, a location- and problem-based structure, and the explicit inclusion of traditional indigenous knowledge (Riggs, 2005). Despite this, field trips are frequently cited as a barrier to indigenous students, due to family or tribal commitments (recognising this will also impact other field-based disciplines) and/or general insensitivity to traditional knowledge around location (Marín-Spiotta et al., 2020; Carabajal and Atchison, 2020) and, in particular, around places to be visited. Similarly, indigenous students face challenges with respect to work placement (including racism, discrimination, misrecognition, and misrepresentation) and were very reliant on positive relationships for successful experiences of the work placement (Pallas et al., 2022).

A recent study has reported that culturally aware teachers, mentors, or practitioners are an important factor in students choosing the geosciences as a career (Todd et al., 2023). Appropriately incorporating traditional knowledge and mentors into geoscience curriculum can improve communication and collaboration across disciplines and cultures as well as encouraging creativity and problem-solving (Smythe et al., 2017). Indigenous research frameworks can enhance higher education by promoting relationality, multi-logicality, and equitable practices in research, teaching, mentoring, and organisational leadership for indigenous students (Reano, 2020).

Recent research in volcanology education has emphasised the use of authentic voices to teach cultural sensitivity and indigenous knowledge across many cultures, particularly where volcanoes hold specific significance (Saha et al., 2021). Cultural competence is an area of educational focus in Aotearoa NZ, and workplaces are increasingly seeking employees with this skill set as the country strives to draw from all available knowledge, uphold the Treaty of Waitangi obligations, and provide equitable educational outcomes for Māori and non-Māori. Māori, the indigenous people of Aotearoa NZ, have their own knowledge system (Mātauranga Māori), and part of this system entails a keen observational and generational understanding of their local area and the history of past volcanic activity (Cashman and Cronin, 2008; King et al., 2008; Tapuke et al., 2019). Regrettably, Mātauranga Māori has been either exploited or marginalised in science education (McKinley, 2005; Smith, 1990; Smith and Ritchie, 2013). Historically, institutional racism has often attenuated Māori experiences in science education, leading to underachievement in traditional measures of learning for Māori students and students from low socioeconomic areas (Macfarlane and Macfarlane, 2018). Braiding of Mātauranga Māori with geology can, thus, lead to increased public preparedness and understanding of these natural processes (Bretton et al., 2018; Gabrielsen et al., 2017; King et al., 2008; Pardo et al., 2015; Swanson, 2008; Tapuke et al., 2019).

The teaching of volcanology frequently underutilises indigenous knowledge sources. The new courses described in this paper highlight the importance of employing indigenous knowledge of areas studied and the benefits that could come from shared and woven knowledge. This work builds on approaches and relationships outlined and defined in Saha et al. (2021, 2022). Indeed, the bicultural content used in the course of our research was in the form of a virtual field trip; in this respect, several videos were reused and repurposed from previous work and additional videos were also recorded or sourced.

2.4 MOOCs and flipped classrooms

The underlying concept of a flipped classroom is that the passive component of learning (the content delivery) is done before class, whereas the active component of learning (discussion, problem-solving, and collaboration) is done with peers

and instructors (Chen and Chuang, 2016; Tan et al., 2017; Karagöl and Esen, 2019). "Content" (reading or videos) is delivered outside the classroom, whereas "homework" (problem-solving with peers and instructors) is done in the classroom (Bergmann and Sams, 2012). However, the application and assessment of the flipped-classroom model is highly variable, and a meta-analysis of data suggests that, contrary to the underlying premise, it is not the active-learning component of flipped classroom that drive measurable learning effects. Interestingly, the use of an additional lecture after online content shows a significant measurable learning effect (Kapur et al., 2022). Kapur et al. (2022) suggest a fail (allow students to struggle with a problem), flip (content delivered), fix (misconceptions are explored), and feed (feedback from students and instructors) model. Although this model is yet to be thoroughly tested, it emphasises the role of allowing students to struggle before or during content delivery when flipping the classroom.

On the other hand, MOOCs are a rapidly growing global phenomenon designed to make education globally accessible and allow students all over the world to learn from the world's best educators. There are many MOOC platforms, and most courses consist of a format of short (3–8 min) videos and a series of questions and discussion boards, the latter of which are variably moderated by instructors and teaching assistants. However, MOOCs have high levels of students not completing courses and students who are disengaged with the content. Small open online courses (SOOCs) also exist to address some criticisms of MOOCs, whereby small cohorts can more easily develop meaningful peer and instructor interactions.

MOOCs and flipped classrooms can be seen as occupying two end-members of the education spectrum in terms of individualised learning. MOOCs are designed to maximise the instructor reach, by making material accessible to a great number of students, whereas flipped classrooms were suggested as an alternative to the traditional classroom to promote active and tailored learning in classrooms by increasing instructor and student interaction. Thus, the learning experience in a MOOC invariably ends up being uniform and less personalised, whereas learning strives to be as individualised and personal as is practical in a flipped-classroom setting. In our model, we drew from Māori education pedagogies to merge the advantages of the MOOC and flipped-classroom formats. We deliver accessible online MOOC content with novel digital assessments and activities as well as face-to-face labs and flipped-style workshops with the goal of developing lecturer–student–peer relationships and skill learning through reflection, discussion, and connection to the online environment. The benefits of working face-to-face and building lecturer–student–peer relationships are well established and highly effective Māori educational pedagogical techniques – kanohi ki te kanohi and whanaungatanga respectively (Kana and Tamatea, 2012; Bishop et al., 2014)

The changes to the course discussed and presented here were developed and implemented before and during the COVID-19 pandemic and at a time when the University of Canterbury had recently signed up to become part of global MOOC platform edX. The COVID-19 pandemic resulted in a growth in online and blended learning, corresponding to an increase in the use of MOOCs (Aristovnik et al., 2023). The post-COVID-19 environment has seen a strong global demand for flexible blended courses, providing both flexibility of online content and opportunities for face-to-face interactions when conditions allowed.

3 Study setting and population

3.1 Course information

The course that was the focus of the research is an elective undergraduate third-year volcanology and magmatic systems portion of a bachelor of science geology degree at a research university (Watson et al., 2022, 2023). The volcanology component of the course, the focus of this study, was redeveloped in 2022 following the successful implementation of an Iceland virtual field trip module (Watson et al., 2022, 2023). The Iceland virtual field trip formed the basis for MOOC development on the edX platform.

The redevelopment was driven by the instructor and informal conversations with Māori students in earlier iterations of the course that resulted in the realisation that there was a missed opportunity to develop skills relating to science communication in the bicultural context of Aotearoa NZ. Of relevance is the strategic aims of the University of Canterbury towards upholding and uplifting Te Tiriti o Waitangi (the Treaty of Waitangi). This includes the inclusion of Mātauranga Māori (Māori knowledge) and promoting the bachelor of science graduate profile of bicultural competence and confidence as essential skills in a multicultural Aotearoa NZ. The course instructor identified improving this outcome of the course as a key goal of this project.

The course development was made possible by a University of Canterbury programme to foster professional development, scholarship of learning, and leadership (University of Canterbury, 2024). Ben Kennedy and Jonathan Davidson were provided with Distributed Leadership in Teaching Practice (DLTP) fellowships to explore the use of MOOCs as tools to help flip the classroom at the University of Canterbury to provide flexible learning solutions for students. The fellowships provided resources and time bought out from regular teaching research and administration duties to develop a second MOOC, implement skill-focused assessment, and develop a model for the university to use MOOCs to deliver online content and facilitate flipping of the classroom.

No student demographic data were directly collected for this research. However, we approximate (1) gender proportions from class enrolments and (2) ethnicity from a yearly university-wide survey to provide readers with an approx-

imation of class demographics. In 2021, 48 % of students identified as women, 50 % of students identified as men, and 2 % of students identified as gender diverse. In 2022, 57 % of enrolled students identified as women, 41 % identified as men, and 2 % identified as gender diverse. In the university-wide survey of university students that were in third-year geology programmes from 2019 to 2021, 73 % of the students were of European descent, 16 % were of Māori ancestry, 3 % were of Asian descent, 3 % were of Pacific origin, and 3 % had other unspecified ancestry.

It is also worth mentioning the impact of the COVID-19 pandemic on these two study populations. Neither cohort was directly impacted by COVID-19 lockdowns during the implementation of this course, although it is worth noting that the 2022 cohort had a larger proportion of their degree affected by COVID-19, particularly missing out on several face-to-face field trips in other related courses as a result of COVID-19 lockdowns during other semesters of their study.

3.2 The development of the course – learning goals, implementation, and materials

The course was significantly changed by adopting a flipped-classroom MOOC. We used the opportunity offered by these changes to intentionally target bicultural competence and science communication skills. We used a constructive alignment approach, a method in which we used our course learning goals to link all assessments (online content, laboratory exercises, and workshop questions), ensuring that all learning is tied back to our original desired outcomes for students taking the course. This was additionally motivated by the university strategy to provide student-focused, flexible, accessible education for all students. In 2021, the course learning goals were as follows:

1. Realise the importance of igneous rocks in geology and to society.
2. Identify and classify igneous rocks and their geological environments.
3. Use geochemistry to explain why magma is generated, diversifies, and erupts.
4. Use geochemical data, thin sections, and maps to reconstruct the magmatic and volcanological histories.
5. Discuss physical volcanological processes with relevance to magma properties.
6. Describe volcanic rocks in the field using examples from Iceland and Aotearoa / New Zealand.

In 2022, a new learning goal was added:

7. Communicate science with different audiences and appreciate the value of Māori knowledge.

Baseline data were collected in August–October 2021. During this period, the course consisted of 6 weeks of volcanology content, two interactive 50 min lectures a week (using in-class exercises and live multiple-choice quizzes), and a 2.5 h hands-on laboratory and workbook (Table 1). The last 2 weeks of the course was devoted to the Iceland virtual field trip, an interactive online module, and two flipped-classroom-style workshops (Table 2). Students wrote a final summative exam during exam week. Course-level learning goals focused around observing and explaining volcanic textures, landscapes, and processes as well as interpreting eruption mechanisms and histories (Watson et al., 2022, 2023). Specific learning goals were outlined in each lecture, laboratory, and online module.

The 2022 version of the course underwent a year of redevelopment working with online learning advisors, Mātauranga Māori advisors, and a community of other DLTP fellows. Online learning advisors helped us design assessments and exercises that aligned with the learning goals and made use of functionality embedded in the edX online learning environment. The edX learning environment provided a range of assessment options with functionality that went beyond quiz questions. In addition to designing quiz-type assessments that provided instant feedback to students, we were able to incorporate peer assessment and reflection to promote engagement and learning at higher levels. The platform also enabled a seamless presentation of content in multiple ways, such as text, video (including 360 video), audio, and interactive content for students to interact with in real time (e.g. interactive graphs, virtual simulations, and interactive maps).

For cultural content and assessment design, we worked with cultural and Mātauranga Māori advisors with whom we had strong existing relationships that had been carefully built and supported through research grants. Previous research showed that shared *relations* and *values* were crucial to create *space for sharing* where challenges and emerging understandings could be repositioned (Saha et al., 2022). Through discussion with our cultural and Mātauranga Māori advisors, we obtained permission to reuse video segments mostly recorded for other purposes (e.g. Saha et al., 2022). In addition, we worked closely with the faculty of science kaiārahi, literally translated as the canoe steerer, but meaning (in this context) a cultural teaching and learning advisor. She helped us embed cultural content and design culturally appropriate assessments to go along with the videos provided by our cultural leaders and Mātauranga Māori advisors. We worked hard to embed the cultural aspects with assessment throughout the course to avoid tokenism, by valuing the content through assessment and reflection.

Similar to 2021, the redeveloped course in 2022 consisted of 6 weeks of teaching; however, now, students were expected to complete 1.5–3 h worth of interactive online MOOC virtual field trip work every week in their own time and attend both a 50 min flipped workshop and 2.5 h of lab

Table 1. Course structure and research data from both runs of the course.

Course run	Implementation and assessment	Research data
2021	A total of 10 h of lectures with assessed in-class exercises, 15 h of laboratory work with an assessed workbook, 4 h of online VFT with assessed online discussion boards, 2 h workshop in last 2 weeks of the course, and study for the exam and a 2.5 h final exam	End-of-course reflection and focus groups
2022	A total of 12 h of MOOC VFT online exercises, 15 h of laboratory work with assessed workbook, 5 h of flipped workshops with an assessed workbook, and a science communication project	End-of-course reflection, weekly reflections, and focus groups

Table 2. Workshop structure comparison from both runs of the course.

2021	Informal discussion with group (10 min) and handout with applied interpretative sketches and reflections (35 min)
2022	Highlighting exemplar online responses from students (5 min), reflection on the confidence of achieving learning goals as guidance for workshop (5 min), warm-up question as mental ramp-up (5 min), mini interactive lecture based on content with low confidence (10 min), and two group workbook questions designed to explore content and develop communication skills (20 min)

work (Table 1). In lieu of a final exam, students completed an applied science communication project that was handed in during exam week (Fig. 1). This change in assessment reflected the shift towards achieving the new skill-based learning goals.

The lab content and work were identical for both groups, and the learning goals were still focused around observing and explaining volcanic rocks and landscapes and interpreting volcanic histories and mechanisms. As mentioned earlier, the key difference was the additional learning goal introduced into all the online modules and workshops, focusing on the skill of science communication to diverse audiences and around developing bicultural competence. Space to achieve these extra learning goals was made by reducing the number of international examples of volcanoes covered in lectures and by focusing on Aotearoa / New Zealand and Iceland only.

Both the 2021 and 2022 versions of the course had online content that is interactive, with 360 videos, 3D rocks, and 3D landscapes (i.e. active, engaging online volcano science content). The 360 videos and virtual rocks and landscapes necessitated students to manipulate 3D space, and most activities had multiple-choice or drag-and-drop questions with feedback provided for incorrect answers that guide students to think again or re-evaluate their thinking in a particular direction (Table 3).

In 2021, the online content was only used during the last 2 weeks of the course. In 2022, the online content was every week, and every module in the 2022 iteration of the course ended with an applied science communication mapping activity. These skill-orientated additional activities were introduced in the online content, in the workshops, and as an additional question in the laboratory workbooks. Some of the online science communication tools in the 2022 version also featured interactive online drawing exercises and peer assessment of other students' answers, with marking rubrics that, in most cases, assessed cultural considerations (Table 3).

In 2022, we developed our flipped workshops (Table 2) to systematically incorporate exemplars of students' online contributions, interactive questions used to promote a mental ramp-up for students (Kapur et al., 2022), and added focus on communication skills in the workbook questions and in class discussion. Additionally, in 2022, at the end of each module, students were asked to rate how confident they were in achieving the learning goals and to justify their responses (Fig. 2). This was implemented to guide the workshop part of the course, in which the instructor would review the student responses and focus on learning goals where students were less confident (Fig. 2). Therefore, the workshop consisted of both lectures, which focused on learning goals where students were less confident, and the reapplication and mastery of content in a different context through a question that needed to be answered in a workbook.

In summary, the 2021 version of the course had many elements of active learning in lectures, labs, and online content, but it lacked learning goal no. 7 "Communicate science with different audiences and appreciate the value of Māori knowledge". In 2021, only the last 2 weeks had a form of flipped classroom. In 2022, the class was truly flipped, aligning better with recent models of flipping of the classroom (e.g. Kapur et al., 2022) and allowing students to fail and reflect.

Figure 1. An example of two pages of a student communication project aimed at educating children about hazards from gases in the city of Goma in the Democratic Republic of the Congo.

Table 3. Details of online content.

Online content	Video	Multiple-choice	Discussion boards	Interactive	End of module
VFT (2021, last 2 weeks)	Instructor and Iceland experts	Content focused	Prior knowledge, reflection, and sketching skills	3D rocks, 360 video, and 3D landscapes	Applied question (and one module with reflection)
MOOC (2022, every week)	Instructor, indigenous leaders, and scientists (Iceland and NZ experts)	Content and skill focused	Prior knowledge, reflection, sketching skills, and communication skills	3D rocks, 360 video, and 3D landscapes; mapping with communication and cultural elements	Reflection after specific goal-achievement exercise

4 Methods

The research used the qualitative evaluation of students' responses to questions in which they were asked to reflect on their learning following a similar methodology to Engel et al. (2023). The study was reviewed and approved by the University of Canterbury's Human Research Ethics Committee (reference no. 92021/116).

4.1 Data sources

We used three different data sources to complete the qualitative evaluation: a student reflection that students completed towards the end of the course, focus group interviews that were completed after each course, and student artefacts from the online part of the course.

In both 2021 and 2022, at the beginning of the final laboratory session of the course, students were asked to complete four reflection questions related to their learning in the course. All students were asked to complete this questionnaire as part of their normal coursework. A total of 21 students agreed to participate in the research (and thus share their reflections) in 2021, whereas 27 students agreed in 2022. This research uses two of these questions as data sources (Table 4):

(Q1) What did you learn in this course and why is it important to you and/or your potential career?

(Q2) Has this course influenced your bicultural competence?

The timing of the questionnaire was immediately after the course content, although before most students had completed their projects. This offered the students a tangible and immediate opportunity to reflect on whether the course had achieved its intended learning goals. The reflective questionnaire served both as a means for students to consolidate their learning and as a data source for our research questions. Reflective questionnaires and journals are a common method in science, technology, engineering, and mathematics (STEM) education research (Boyle et al., 2007; Scott et al., 2019; Treibergs et al., 2022). The first question offered an open-ended opportunity for students to think about what they learnt without being prompted towards thinking about learning goals or specific skills. The second question was targeted towards the specific learning objective of bicultural competence, which aligns with a university-wide graduate attribute.

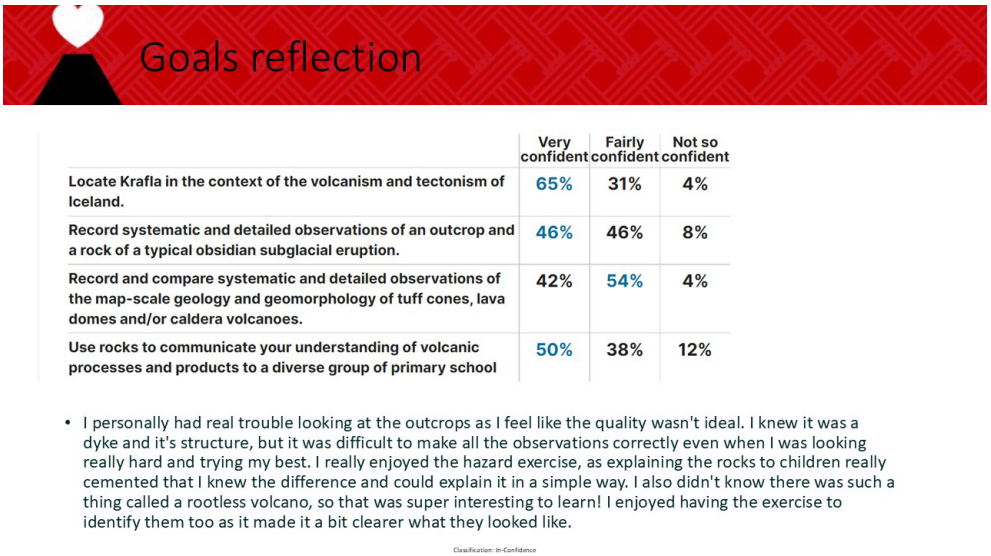

Figure 2. Example slide from the start of a workshop session in 2022, showing learning goals, a summary of student self-reported confidence on learning goals for the module, and one example justification from students. This slide shows how learning goals are constructively aligned by giving students the opportunity to self-report and reflect on their achievement of the goals.

Focus groups were held after the last week of class in both years. The focus group interviewer asked several questions related to the course changes. The main questions relevant to this research were as follows:

- How has the course affected the way you feel/think about your bicultural competence and confidence?
- How has the course affected the way you feel/think about your science communication skills?

The focus groups were run after the course had ended but before the final exam or project was completed. A total of 10 students participated in 3 focus groups in 2021 and 7 participated in 2 focus groups in 2022.

We also used student artefacts from two courses as a source of data. In 2022, at the end of each module, students were asked to rate how confident they were in achieving learning goals and to justify their responses. These responses, as well as other responses to open-ended discussion questions throughout the course, were additionally analysed to explore whether a specific part of the course led to perceived improvements in achieving the learning goals relating to communication skills or bicultural competence. A total of 6 end-of-module questions and 11 discussion questions were analysed.

4.2 Data analysis method

4.2.1 Reflection questionnaire

Students' reflection responses were coded by breaking down the two questions into sub-questions to help analysis (Table 4). Each questionnaire was then coded according to these sub-questions using coding categories. For example, Question 1 of the questionnaire was simplified down three sub-questions "What was learnt?", "Is what you learnt important to your future career?", and "Is what you learnt important to you personally?" (Table 4). Student responses to these questions underwent a first-order coding with respect to content knowledge, skills, or attitudes.

An example of how an answer is coded is shown in a response to the reflections question Q1 (Table 4).

> This section of the course has taught me heaps! I loved learning more about the different types of volcanic eruptions, how they form, and the hazards associated with different eruptions. I can see how understanding these fundamental concepts will be valuable going forth into a geologist career. As well as learning about geology, this course also strengthened my ability to be curious and excited about things and ask questions. It was very eye-opening hearing Ben's reflection of the Whakaari disaster, as before hearing his perspective I had never considered this implication between science research and human safety of a tourist destination.

In this quote, the student stated that they had learnt about content knowledge, including different types of volcanic eruptions, how they form, and the hazards associated with different eruptions. They also mention that the course gave them an understanding of fundamental concepts that would be valuable for a geology career. Lastly, they state that the course helped strengthen their curiosity and made them excited to ask questions. It also changed their perspective on science research and human safety at a tourist destination

Table 4. Coding methodology. The values reported in the columns are the number of students that mentioned the category in their reflections, and n is the total number of answers.

Reflection questions	Question aspects	Coding categories	Results	
			2021 (total $n = 21$)	2022 (total $n = 27$)
(Q1) What did you learn in this course and why is it important to you and/or your potential career?	What was learnt?	Content knowledge (factoids)	21	23
		Skills	18	26
		Attitudes	11	4
	Is what you learnt important to your future study/your career/you personally?	Yes	17	21
		No	1	0
		Not stated	3	4
(Q2) Has this course influenced your bicultural competence (BCC)?	Did the course improve your BCC?	Yes	9	25
		No	8	1
		Unsure	3	1
		Not stated	1	0
	What kind of cultural knowledge was improved?	Māori	5	17
		Icelandic	8	1
		Other	1	7
		Not stated	12	2

such as Whakaari. This answer was marked as a student having gained knowledge of a factoid and changing their attitudes towards learning and thinking. This student did not mention anything about skills gained. This method was utilised for both questions in the questionnaire across all years of this study.

4.2.2 Focus groups and discussion boards

Focus groups were recorded and then transcribed. The questions asked during the focus group were formulated to supplement the questions asked in the reflective questionnaires. These questions and their equivalent in the reflective questionnaires are presented in Table 5. The discussion board data were analysed to track if a comment was related to biculturalism or science communication. Both the focus group and discussion board data are used to supplement the data from the reflective questionnaires to clarify and drill deeper into the meaning of the data.

5 Results

We report course reflections on learning in 2021 and 2022 that related to learning skills, and we specifically code our analysis for bicultural competence and science communication. We also present focus group discussions and specific student reflections within the course that related to either bicultural confidence; science communication; or specific pedagogies, activities, or course elements.

5.1 Overall learning

The analysis of student reflections on "What did you learn in this course, and why is it important to you and/or your potential career?" (Q1) showed that, from 2021 to 2022, there

Table 5. Focus group questions mapped onto the reflective questionnaire questions.

Focus group questions	Reflective questionnaire equivalent
How has the course affected/influenced/helped/assisted your learning in volcanology/geology?	(Q1) What was learnt? (facts/attitudes)
How has the course affected the way you feel/think about your science communication skills?	(Q1) What was learnt? (skills)
How might your experience with the course help you in the future?	(Q1) Is what you learnt important to your future study/your career/you personally
How has the course affected the way you feel/think about your bicultural competence and confidence?	(Q2) Has this course influenced your bicultural competence (BCC)?

was a 13 % increase in comments on learning that related to skills when compared with learning content or general attitudes (Fig. 3, Table 4). When these skills were categorised by types of skills, students in 2021 were more likely to mention skills relating to data or other skills such as microscope skills, whereas students in 2022 specifically mentioned bicultural competence and communication as well as flexible learning skills (Fig. 4).

In 2021, students were more likely to mention content knowledge and other skills relating to the laboratories; for example,

> I learnt different aspects of volcanology and magmas, this is crucial in understanding volcanic environments and deposits as well as using microscopes to identify different minerals in thin section and understand how this can relate to magmatic environments. This could be applied to many careers outside of volcanology, the skills taught in this course are essential for any geologist.

The student mentions that they learnt about different magmas (content knowledge) and using microscopes (skills). They also address the second part of the question and mention that the skills learnt in the course are applicable to many careers outside geology and are essential for any geologists. Other students' responses focused on content knowledge, and several students and did not mention any benefits to their future career; for example,

> The effects of a volcano on the surrounding area in the form of ash and bombs etc. different types of magmatic flows and what moves them such as gas content and if they're mainly juvenile etc.

5.2 The learning environment

Although the reflection question focused on *what* was learnt, many students mentioned *how* they learnt, and this was coded as a skill in both years' analyses. Particularly, the freedom to work at their own pace was commonly mentioned in the reflection exercise:

> Helps me be able to go at my own pace, and not having to sit in one spot and watch a 50 min straight lecture which is very boring and mentally draining.

> The online modules were a very different way of learning than I was used to, and I think I can take lessons of time management, persistence and quizzing from it. I think that my time management started poor, but found that when I was able to push through the temptation for distraction… I also liked how the online work quizzed me after introducing a topic, and I think that this is conducive to my learning

> The modules allowed me to work at my own pace and better understand the material as I could go back and re-watch videos or re-attempt an answer if I got it wrong, which helped me figure out what I needed to focus on more within the modules and my learning. Allowing us to re-attempt the questions and self reflect/mark showed that I learn from making mistakes and emerging myself within a topic more which was helpful.

> I have enjoyed the small quiz questions directly underneath the content that introduces what the questions will be about, it keeps the knowledge fresh for the questions.

This flexible blended learning environment was seen as a positive development, especially the ability to work at their own pace. Some students identified their own growth in time management skills. The frequent quiz questions associated with content were also positively mentioned several times.

Overall, after the intervention, students identified communication and bicultural competence skills as well as flexible learning more often in their reflections, with less mention of content knowledge and attitudes.

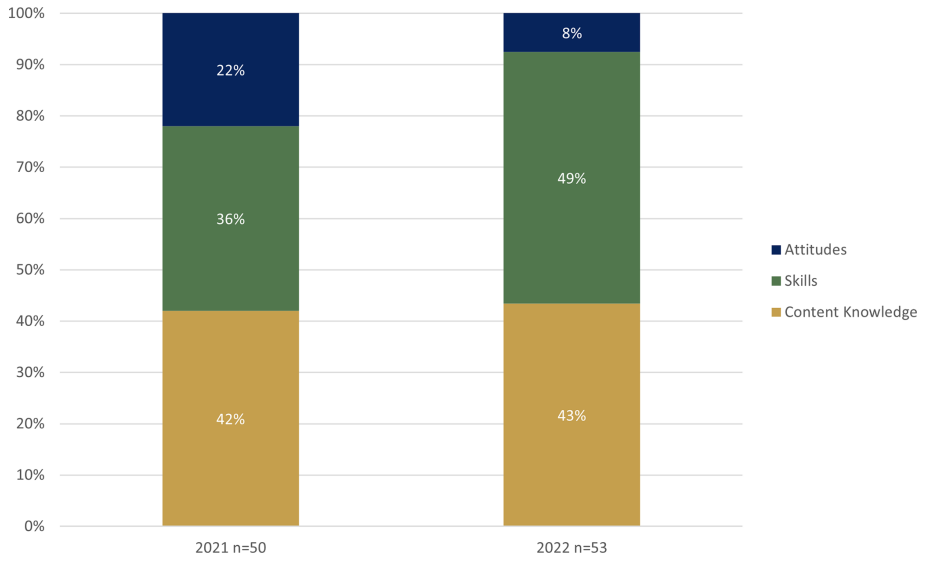

Figure 3. Relative coding results from reflection data. *n* is total number of the code category mentions. (One answer might have multiple mentions.)

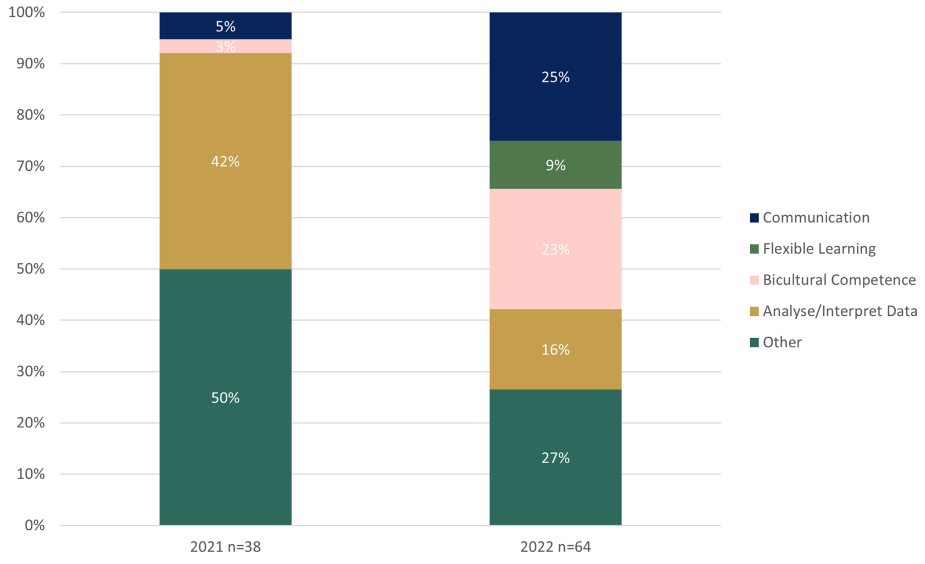

Figure 4. The 2021 and 2022 data comparison of skills mentioned by students in their reflections. (One answer might have multiple mentions.)

5.3 Specific aspects of the course linked to learning by students

Students specifically regularly mentioned exercises in a positive manner. Students appreciated the models and maps that were part of the course as per some student reflections (this is consistent with previous studies, such as Watson et al., 2023):

> The online lectures really helped with outcrop descriptions and 3D visualisation. the use of models and maps in this course was AMAZING, and I really found they helped my understanding of the larger scale geological processes which the course was trying to teach us.

Students mentioned the specific assessment exercises; for example, in the reflection at the end of a module, this student mentioned an open-answer question that was asked in that module:

> It also was directly linked to what we were learning about like with the geothermal resource email to the Māori land owner, rather then randomly being brought in every now and then unrelated to what was goin [sic] on … I also like that there were

> Māori experts in their fields who were directly teaching some of the concepts, that was great.

In the focus groups, students mentioned that they appreciated the guided method used to teach skills through applied exercises:

> I think those sorts of yeah [exercises], like none of my other courses have really touched on that and having that like guided approach through it and like I think it's definitely a cool skill that I have like obtained um, cos it's not just yeah, like rote learnt knowledge.

Practicing the procedure in different contexts and with different target audiences was seen as a beneficial, helping cement concepts, as per this quote from a focus group participant:

> Um, maybe just adding to, I think having the multiple different tasks, like with concepts, so you constantly had to think about the science side and the like, bicultural perspective but in different formats… a Facebook post which is, you know super, … and then you had one where it was like an email where you sort of had to be like, okay this is a different format but the same thing and then talking to little kids, you're not going to use the same words, same terminology, the same approaches to all of those things.

5.4 Communication skills

In 2022, students typically mentioned communication skills which were coded as either general communication skills or part of bicultural competence in the case of specific bicultural communication:

> The biggest thing I learnt in this course way [sic] how to communicate scientific ideas to a non-scientific community in a way that helps them understand the ideas without creating distress or make [sic] them feel that their culture is not heard and appreciated. This is a skill that I will use within my future career when dealing with any people, both coworkers and people within the public.

> This idea of respectful communication is something that would be important wherever I go, and is something that I hope to be able to practice in the future.

These are typical examples of student responses in 2022. The student mentions that they learnt how to communicate (science communication). They also mention culture (bicultural skills). They do not mention any content knowledge; however, they do acknowledge that the communication and cultural skills that they gained will be important in their future career. Some students did not link their skills learnt to their future career, but they did mention content knowledge and the importance of bicultural communication:

> I learned a lot about NZ and Iceland volcanoes and how they compare to each other. I also learned about some mitigation strategies and how to categorise different types of volcanic eruptions. I also learned a new way of learning online through these videos and answering the questions as I go through. I learned about incorporating Māori knowledge and the importance of Māori involvement with geothermal projects.

Student's reflections at the end of the module also mentioned the same sentiment. In the next three quotes, students discuss the value of an exercise where students were asked to comment on the following fictional social media post (posted by John B): "I have heard volcanoes erupt after earthquakes and I know Lyttleton [sic] volcano has had an explosive history, I also read in the news that there are some hot springs that have got hotter since the earthquake, I am not sure if I could cope with lava on top of everything – does anyone know if the volcano will erupt. ":

> I thought this was a very relevant module that taught me skills that I will definitely use. I quite often see misinformation or posts similar to John's, and I usually avoid them because I don't know how to approach them. This module gave me the skills to do so.

> I found this module rather enjoyable, a lot of the time social media can provide a lot misleading information that can generate unwanted fear in people or provide incorrect information to people that can then be passed on. To be able to politely critique a member of the general public and guide them towards more reliable scientific information.

> I enjoyed this module as I have seen posts on social media that were not well communicated, so learning better ways to communicate was nice to see.

These reflections show that the students felt the exercises were authentic and relevant to their learning journey.

5.5 Bicultural competence and confidence

The reflection question "Has this course influenced your bicultural competence?" (Fig. 5) showed that only 43 % of students in 2021 thought that their confidence was influenced, whereas this number increased to 93 % in 2022. When the student answers were coded during exploration, it was apparent that bicultural competence was interpreted as also knowing about the Icelandic experience with volcanoes by many

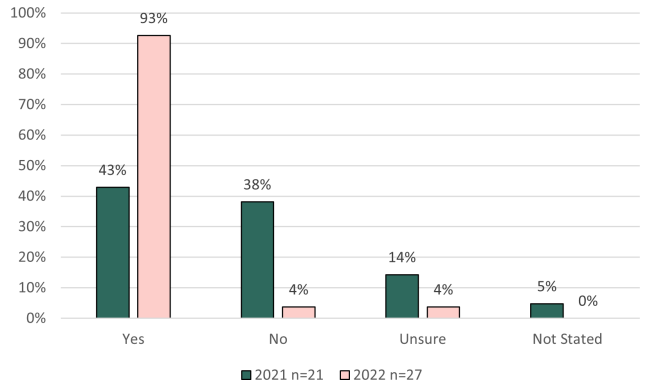

Figure 5. Summary of cultural competence perception in student reflection questions.

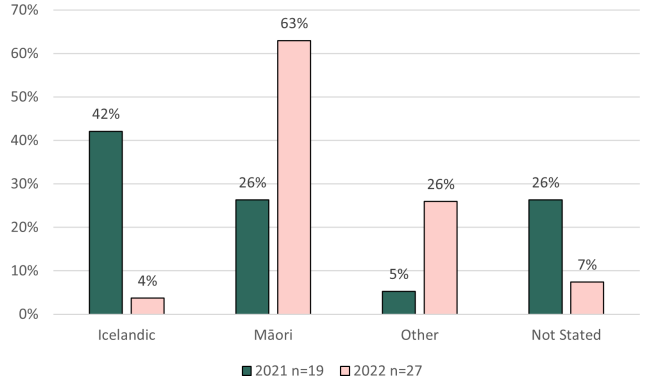

Figure 6. Summary of the cultural influence type mentioned in student reflection questions.

students in 2021 (Fig. 6); this is not a surprise given that most of the virtual field trip in 2021 was set in Iceland and featured Icelandic locals and narratives. This is illustrated by the quote from a student reflection response:

> I think the Iceland trip perhaps enhanced my bicultural knowledge on how other communities deal with volcanic hazards.

A typical student response from 2022 was as follows:

> This course has definitely influenced my bicultural competence. I have gained a better understanding of Māori and Icelandic cultures and the importance of being culturally sensitive when communicating information.
>
> Absolutely, this is the course that has gone most into it. In a lot of other courses I feel as though it is only really mentioned at the start maybe fore a mihi [sic] and then is forgotten about has [sic] the course goes on, but here it was brough [sic] through out the whole course which was cool. It also was directly linked to what we were learning about like with the geothermal resource email to the Māori land owner, rather then randomly being brought in every now and then unrelated to what was goin [sic] on... I also like that there were Māori experts in their fields who were directly teaching some of the concepts, that was great.

The focus group transcriptions and discussion board responses also revealed the value that the course contributed to the student's bicultural confidence (Table 5). One example from a focus group discussion is as follows:

> Yeah, I think the communication side of it was probably the most beneficial that I got out of the course, um, especially yeah I suppose interacting with like manu whenua Māori and um, and even just how to, I suppose adapt your communication to particular audiences.
>
> I feel like this part of the course has been very inclusive of what is the indigenous approach to this, what is the cultural understanding, how can we incorporate the sort of more indigenous aspects into how we approach science sort of like with the braided rivers approach.

In this quote, the student shows a new appreciation for adapting their messaging to different cultures.

The following quotes from focus groups interviews in 2022 show that students value bicultural confidence and competence skills:

> ... especially in New Zealand, it's so important to incorporate that indigenous knowledge when it comes to how we approach science.
>
> I feel like this part of the course has been very inclusive of what is the indigenous approach to this, what is the cultural understanding, how can we incorporate the sort of more indigenous aspects into how we approach science sort of like with the braided rivers approach...
>
> I think it is a good reminder that a bicultural approach is necessary, especially within the work place. I really liked how Ben used the karakea [sic], as I felt it tied the course up nicely, beginning to end.

Students were very interested in the actual content and expressed that they would like to get a deeper understanding of the subject, as shown by the following discussion board quotes:

> I found the Māori volcanology legends fascinating and I would love to learn more about how they view volcanoes and how we can use a mixture of both Western and Māori knowledge to inform hazards and risks.

> Learning about the volcano family, particularly in the context of Māori mythology is an interesting idea that we often don't get to experience as science majors. Very cool!
>
> I also enjoyed the input from Dan, on the ways we can implement Māori/ native cultural information, as you currently don't see a large amount of scientific literature with consideration of these kind of inputs.

6 Limitations

The research and the course assessment were intertwined; for example, the instructor was also one of the researchers, and parts of the assessment (the reflections and discussion boards) were used as research artefacts. However, marks for reflections and discussion boards were only for completion, and the student answers were anonymised before the instructor saw them (e.g. Watson, 2022), as per the ethics agreement. Similarly, when the research was presented to the students and their participation in the research was requested, the instructor was out of the room, as per the ethics agreement. However, considering that the research relies on the students' perception of their learning, it is possible that students' perception of what they were learning was influenced by the research. Given that this study is a comparison between 2 years and that the research methodology was identical in both years, comparisons between both cohorts should be uninfluenced by the research.

7 Discussion

By comparing the results from the two separate classes, we can get some insight into the effect of the course changes. The analysis shows that students in the post-intervention group were more likely to mention skills in their reflections on what they learnt (Fig. 3). When analysed further, the skills that were mentioned were most likely to be related to communication, online environment, and bicultural competence. This increase in mentioning skills aligns with the instructors' goals for the changes implemented in the course, which were specifically to improve the communication skills and bicultural confidence of the students (Fig. 4).

Overall, the student reflections show that the change from a lecture-based classroom setting to a flipped classroom with an interactive, engaging, and pedagogically grounded online environment was an effective classroom intervention. The 2022 iteration contained more interactive elements and functionality aligned with communication and bicultural competence. It also provided more authentic assessment and opportunities for deliberate practice (e.g. Benjamin and Tullis, 2010), which are pedagogical approaches that are linked to improved learning. The delivery of both the 2021 and 2022 content took place during the COVID-19 pandemic, although neither year was directly affected by lockdowns, and the reflection questions analysed here did not address the impact of the COVID-19 pandemic on learning, although this context is important to consider, as it has been shown to influence students' and instructors' opinions of online learning (Chakraborty et al., 2021).

The intervention contained additional exercises to encourage students to engage with class material outside of the classroom and apply what they learned to real-world situations that they expect to experience in a future career. These exercises can be defined as authentic assessments (Kaider et al., 2017). Students linked these authentic assessments with their perceived learning in the discussion boards, reflective posts, or focus groups, where students reflected on specific exercises linking these exercises to learning specific career-useful skills. Students' quotes showed that they felt that the course provided them with opportunities to practice skills to communicate effectively. They felt that these authentic assessment exercises could help them develop skills that could be useful in future careers. Some quotes reveal that these skills were something that the students had already encountered in their personal lives and, therefore, valued as authentic. These skills are not only related to the courses' learning goals but can also be linked to the University of Canterbury's bachelor of science graduate attributes of being "Biculturally competent and confident" and "Employable", specifically around "Communication". Although not directly related to a specific geology career, they are, in essence, skills required to become an informed bachelor of science graduate and citizen.

A clear change between both cohorts is the bicultural confidence context that students mentioned in their reflections. In the 2021 cohort, most of the group discussed Icelandic culture when asked about bicultural confidence and competence, whereas almost all students took it to mean Māori culture in the 2022 cohort. Although this in not the case overseas (e.g Clark, 2006), in Aotearoa / New Zealand, biculturalism specifically refers to the existence of two distinct cultures, Māori culture and New Zealand culture, with the latter based primarily on values from British settlers (Eketone and Walker, 2015). This latter definition of biculturalism is relevant here and when interpreting students' responses regarding bicultural confidence and competence in the reflective questionnaire in both years. That students mentioned Māori culture less in 2021 is likely related to the lack of Māori experts and assessments relating to bicultural confidence featured the 2021 version of the course; therefore, the students might have felt that bicultural confidence in the context of the course did not specifically relate to Māori culture. The 2022 data show that bicultural understanding was at least partially shifted and was related to the Māori experts featured in the course and the related assessments. Improved cultural competency has been reported to enhance people's well-being by

bringing together indigenous and non-indigenous knowledge and practices (Eketone and Walker, 2015).

Students' quotes generally showed a genuine appreciation for the Mātauranga Māori and bicultural content. Reflections showed that the content in the 2022 version of the course felt authentic and better integrated compared with other courses. Students appreciated that the instructor lead by example by adhering to Māori tikanga (customary practices) while delivering the course. Our model of an MOOC, a flipped classroom, and a focus on developing lecturer–student–peer relationships is an expression of Māori tikanga, and it enabled students to experience it by undertaking the course. For example, students experienced whanaungatanga (meaning "creating cohort connection through relationship building" in this context) via the intentional relationship building and, further, by writing and sharing their pepeha as well as reading other students' pepeha – an activity that the students highlighted in their reflections. Students also commented that they appreciated videos shared by our cultural experts, where cultural values were frequently expressed such as kaitiakitanga (intergenerational sustainable guardianship of the land) around the geothermal industry.

8 Conclusions

Our research describes the pedagogy behind our course and the critical roles that all the members of the team had in course development. We then present and discuss data on students' perceptions of their learning and how this relates to elements of the course.

Learning advisors guided us to produce engaging interactive activities on the edX online platform, and these were critical in allowing the creation of activities that enabled the deliberate practice of skills in a variety of assessment types. Similarly, our cultural advisors also delivered authentic content, providing essential mana and expertise in cultural knowledge and how to design assessments that reflect and test this knowledge. These roles were essential to achieve the learning associated with skill-based learning objectives in 2022, and this was in addition to the critical roles of the instructor and 3D visualisation tools developer, as discussed in Watson et al. (2022, 2023)

Students in 2022 were more likely to mention communication skills, bicultural skills, or skills relating to flexible learning when asked to reflect on their learning. Several students in 2022 specifically mentioned the newly introduced authentic assessments and linked this to their skill learning. Some students also mentioned the opportunity to practice skills in a variety of contexts and using a variety of tools.

The team-based development of the flexible course, with multiple experts and repurposing of videos, should provide a template for the development of other courses with skill-based course learning goals. In addition, the research supports the use of multiple flexible modes of authentic assessment to promote skill-based learning.

In summary, students' reflections showed that they gained bicultural confidence and communication skills during the course. Our consideration of Māori tikanga, Mātauranga (knowledge), and values such as kaitiakitanga (guardianship) and whanaungatanga (relationships) alongside scientific methods fostered the ability to communicate science with a range of people with different academic and cultural backgrounds, which is important in most careers in Aotearoa NZ and globally. We encourage other academics to uphold local indigenous cultural perspectives when developing and delivering science courses.

Data availability. The data used for this study are available here: https://doi.org/10.26021/canterburynz.28700828 (Kennedy et al., 2025).

Author contributions. BK and JD designed the experiments and JD and KE carried them out. All authors contributed to the design and redevelopment of the course. BK prepared the manuscript with contributions from all co-authors.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Ethical statement. The study was reviewed and approved by the University of Canterbury's Human Research Ethics Committee (reference no. 2021/116).

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