Jupyter Book as an open online teaching environment in the geosciences: Lessons learned from Geo-SfM and Geo-UAV

Peter Betlem[1, 2, 3], Nil Rodes[1], Sara Mollie Cohen[1], and Marie A. Vander Kloet[1, 4]

[1]The University Centre in Svalbard, Longyearbyen, Svalbard, Norway
[2]Norwegian Geotechnical Institute, Oslo, Norway
[3]Department of Geosciences, University of Oslo, Oslo, Norway
[4]Department of Education, University of Bergen, Bergen, Norway

Correspondence: Peter Betlem (peter.betlem@ngi.no)

Abstract. Together with our students, we co-created two open-access geoscientific course modules using the Jupyter Book environment~~and appraised the environment's~~ . We also assessed the Jupyter Book environment, integrated with GitHub to facilitate versioning, for its suitability for co-creation and open learning. The modules ~~were iteratively revised over a four-year period and covered the acquisition of drone data and subsequent processing of digital outcrop models. Each module~~ implemented an in-line collection of videos, animations, code snippets, slides, and interactive material to complement the main text in a diverse open learning environment ~~. Behind the scenes, was used to facilitate content versioning, co-creation~~ that is free and open to all. The modules' main topics included the geoscientific acquisition of drone data and subsequent digital outcrop model processing, but also touched upon scientific problem solving and documentation. The two modules were iteratively revised over a four-year period, steered through student contributions and pedagogic feedback. Student-collaboration and ~~open publishing of the resources. We found that students approved the framework and especially valued the framework' s~~ co-creation fostered an interest in revising and updating the educational materials, with the important note that students were given ample introductions to the tools and time. We evaluated the framework and modules through in-class feedback, and students and external users were invited to participate in an online questionnaire. Responses revealed the educational usefulness of the Jupyter Book/GitHub framework, and that students valued the modules' accessibility, inclusivity, co-creation capabilities, interactivity, and ~~use of animations and multimedia . Collaboration certainly helped cultivate an interest in both student and instructor to revise the source materials and updating information where it was deemed outdated or unclear, regardless of the contributor's background, affiliation or level of experience. However, we found that effective co-creation relied on students being familiar with the tools at their disposal, plus be given the opportunity to contribute in their own ways. Through our combined efforts, we~~ blended use of text, multimedia and animations. In summary, we succeeded in providing lasting, up-to-date and open course materials to a campus with a small department that does not have significant experience nor capacity in developing and maintaining open educational resources. ~~Finally, although we established their use, work remains to establish optimal implementations for educational GIFs~~Herein multi-disciplinary collaboration and student co-creation were key.

1 Introduction

~~The concept of openness and sharing is central to many disciplines, particularly~~ Openness and sharing are key in many fields, especially in teaching, research, and software (Khan and Ur Rehman, 2012; Hockings et al., 2012; Abernathy, 2023; Jhangiani and Biswas-Diener, 2017). ~~Within educationspecifically~~In education, open pedagogy (OP) ~~envisions~~ promotes a more democratic, accessible, and affordable learning environment by using open educational resources (OERs) ~~and avoiding expensive proprietary materials (Wiley and Hilton, 2018; Abernathy, 2023; Wiley and Hilton, 2018; Christiansen and McNally, 2022; Har~~ ~~. In so doing, OP emphasizes transparency, collaboration, and student-driven learning (Hegarty, 2015).~~

~~Despite its growing adoption, OP remains far from a formalised standard. Rather, it is a set of aspirational guidelines encouraging the creation, adaptation and sharing of educational materials (Wiley and Hilton, 2018; Christiansen and McNally, 2022; Tietje~~ ~~. Herein OERs and OER-enabled pedagogy (OER-P) play an important role and have seen an update in recent years as an alternative to conventional scholarly and educational publishing (Tietjen and Asino, 2021; Wiley, 2013; Wiley and Hilton, 2018)~~ ~~. Through~~ instead of proprietary materials (Wiley and Hilton, 2018; Abernathy, 2023; Wiley and Hilton, 2018; Christiansen and McNally, . OERs allow for retention, reuse, ~~revision, remix~~revisitation, remixing, and redistribution ~~, OERs have the unique opportunity to deliver inherently collaborative, transparent workspaces and innovations~~ (5Rs), fostering collaboration and transparency that extend beyond the original ~~authoring institution or idea (Audrey Azoulay, 2019; Caswell et al., 2008). OERs also inherently enhance~~ creators (Audrey Azoulay, 2019; Caswell et al., 2008). They also increase the visibility and accessibility of educational content, ~~promoting wider~~ encouraging broader participation (Jhangiani and Biswas-Diener, 2017; Barba et al., 2019).

~~Certainly, OERs are hardly new to education; however,~~ However, what could or should “count” as OERs has become a source of concern for scholars and advocates who note the casual use of the term “open” for materials that neglect or obstruct the 5Rs of OER (typically because of copyright restrictions) (Wiley and Hilton, 2018). It can be useful then to consider how “openness’ can be understood and assessed, which should ideally be done in tandem by both educators and students.

Importantly, co-creating OERs with students increases diversity in teaching materials, enhances engagement and improves learning outcomes (Biddle and Clinton-Lisell, 2023; Lambert, 2018; Kelly et al., 2022; Nusbaum, 2020). Overlapping with ~~scholarship on~~ the Students as Partners ~~,~~ approach, OER-enabled pedagogy (OER-P) strategies enable what Bovill and Woolmer (2019) describe as co-creation *in* curriculum and co-creation *of* curriculum. This approach balances power dynamics between teachers and students, reframes knowledge and knowledge production, and "counters the increasing commodification of learning" (Bovill and Woolmer, 2019, p. 408). It is from this point ~~,~~ that our project emerges - we are curious about the potential of OER resource development as a transformative pedagogical practice that is undertaken collaboratively with students.

1.1 Jupyter Books as a tool for OER development

Today, OP and OER-P benefit from a rich ecosystem of open tools like Project Jupyter, which promotes open standards and ~~checks many of the openness requirements~~ collaboration (Project Jupyter, 2023; Granger and Perez, 2021). Jupyter helps ~~decompose~~ break down problems and tell stories with code and data~~through a range of tools of which the computational Jupyter Notebooks are perhaps most famous (Granger and Perez, 2021; Project Jupyter, 2023). It is thus not surprising that it is used widely~~ , with Jupyter Notebooks being the most well-known tool (Granger and Perez, 2021; Project Jupyter, 2023). Jupyter and related tools are widely used in data science, machine learning, scientific computing, and ~~even~~ teaching. Recently, the Jupyter Book environment has emerged as an ~~extention that extends~~ extension of the computational Notebook environment ~~with~~ to include narrative and multimedia content (Executable Books Community, 2020). ~~Simply put, Jupyter Book provides an interface for building~~ Jupyter Book allows for creating publication-ready books that integrate computational content (~~"Jupyter Books") that seamlessly integrate computational (~~e.g., Jupyter Notebooks, ~~programming~~ scripts) and narrative content (e.g., text~~files~~, images, videos) ~~content (Executable Books Community, 2020). The resulting~~ (Executable Books Community, 2020) . These user-editable "unbooks" (Woodworth, 2011) ~~integrate easily~~ work well with co-creation and version control ~~solutions like gitand are~~ tools like git, making them ideal for open publishing.

~~In this contribution,~~ This manuscript documents the implementation of Jupyter Book and GitHub in two geoscience undergraduate modules on UAV data acquisition and SfM photogrammetry processing, as part of a transition to OER-P teaching at a small campus. Specifically, we test whether Jupyter Books can indeed act as a diverse, equitable, and inclusive learning environment ~~, embracing the three pillars of "open" social justice: redistributive, recognitive, and representational~~ suitable for OER-P (Lambert, 2018; Biddle and Clinton-Lisell, 2023). First, we evaluate the pedagogical potential of ~~co-created~~ co-creating Jupyter Books, ~~evaluate the resource's~~ their openness, and ~~assess our students'~~ student's learning experiences. Second, we assess whether the Jupyter Book/~~framework and~~ GitHub co-creation ~~can be used for OER development with only~~ framework can develop OERs with limited resources. Third, we ~~appraise~~ examine student reception to the multimedia environment ~~, as well as~~ and conduct a brief study on optimal playback times versus ~~student retention to optimise the use of animation versus videos in future module designs. In order to accomplish the above, this manuscript first documents the implementation of Jupyter Book and in the design of two geoscience undergraduate moduleson unmanned aerial vehicle (UAV) data acquisition and structure-from-motion (SfM) photogrammetry processing, respectively, as part of a transition to OER-P teaching at a small campus. It then demonstrates the openness and accessibility of the framework (including the use of animations), assesses user and student learning experiences, and appraises the framework's co-creation possibilities.~~ retention to optimize animation and video use in future modules.

2 Methods and data

2.1 Context and participants

This study was conducted over 4 years as part of two geology courses at the University Centre in Svalbard (UNIS), a small public university centre in ~~northern Norway~~the Norwegian Arctic Archipelago of Svalbard. Both courses were taught ~~asynchronously during a~~ and applied asynchronously throughout the semester, with physical tutoring hours available over a one-week ~~interval by the same instructors, with all materials provided online~~period. All materials were provided online, and follow-up discussions taking place both digitally and in person. Class sizes ranged from 10 to 20 participants with diverse Earth Science backgrounds.

Course 1: An annual undergraduate geology course focusing on geoscientific digital techniques (n=62 over four years). Activities included digital field notebooks, data acquisition, geological model generation, and multi-physical data integration.

Participants were primarily western European and Scandinavian students, requiring at least 60 ECTS in natural science, including 30 ECTS in geosciences.

Course 2: A multidisciplinary short course (n=10) on UAV-based data acquisition and processing, offered in summer 2023. Participants had diverse educational backgrounds, including scientific and technical staff, and students from various science, technology, engineering, and math (STEM) fields.

The Geo-SfM module (Betlem and Rodes, 2024) was implemented as part of Course 1 in 2021, initially taught digitally due to COVID-19 and redesigned from a previous teacher-centric module~~taught previously~~. It introduces structure-from-motion photogrammetry and provides detailed best practices. Subsequent years saw in-person teaching with ~~minor~~ revisions based on ~~colloquial and questionnaire feedback~~ feedback collected through classroom discussion and questionnaires.

Course 2's syllabus includes the Geo-SfM and Geo-UAV modules. The Geo-UAV module (Rodes et al., 2024) teaching UAV-based data acquisition and processing, providing self-explanatory recipes and tutorials on legal frameworks, piloting, and data acquisition. Both modules were developed from experiences and best practices from the Svalbox project (Senger et al., 2021; Betlem et al., 2023). ~~Fieldwork tested the portability of Geo-UAV, implementing either the online tutorials or exported PDFs while teaching in the field~~Course 2 was a direct result from collaboration with the UNIS logistics department, which sought to bring attention to the usability of co-creation and shared resources across departments.

2.2 Module and course design

We designed the Geo-SfM and Geo-UAV modules to facilitate an inclusive, accessible, and diverse learning environment. Our design drew inspiration from textbooks and tutorials using Sphinx and Jupyter Book (Henrikki Tenkanen et al., 2023, 2022; Lehmann, 2011; Executable Books Community, 2020; Rhoads and Gan, 2022; Community, 2022), which integrate interactive components and narrative content. Jupyter Book was chosen to integrate all course content, with sessions increasing in difficulty and depth, including introductions, background information, multimedia content, tutorials, and assignments. ~~Mini-lessons~~ Mini lessons on project management, data structuring, and automation were also included.

~~Following an introduction to the layout of the modules, sessions~~After introducing the module layout, sessions, and key learning outcomes, students were ~~introduced to the platform (i.e., the backend) and requested to sign up and raise a simple welcome/~~shown the GitHub platform. They signed up and raised a simple "hello world" issue ~~through one of~~ via the on-page menu bars at the ~~start of the respective courses. This was done to facilitate optimal use of the collaborative framework and allow the students to familiarise themselves with the~~ course start. This helped them get familiar with GitHub's backend, including the issue tracker and online feedback ~~solutions. The students were then asked to work~~ tools. Students then worked through the course modules in pairs, ~~applying the concepts of~~ using pair learning to ~~further enhance collaborative learning~~ enhance collaboration (Nagappan et al., 2003; Drey et al., 2022).

The GitHub platform, including its Classroom tools, has ~~previously~~ been shown to improve the educational experience for students and teachers (e.g., Zagalsky et al., 2015; Fiksel et al., 2019)~~, and~~. It also facilitates open hosting of documentation and (static) webpages, which eases Jupyter Book publishing. The use of GitHub allowed detailed tracking of suggestions and corrections ~~proposed by the~~ from students and other participants, ~~thus~~ forming the backbone ~~to~~ of the co-creation and

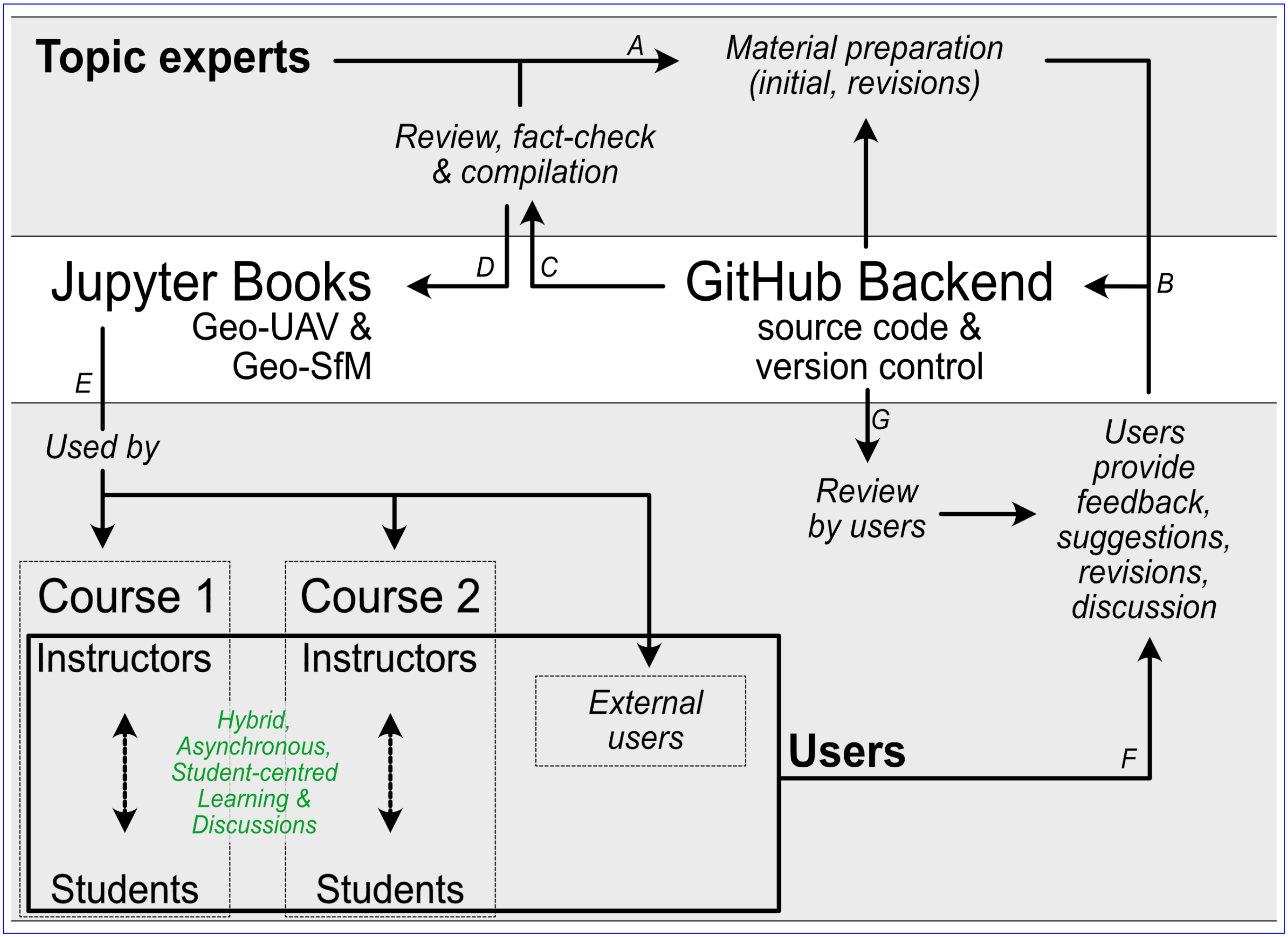

Figure 1. Instructional approaches of Geo-SfM and Geo-UAV integrating the GitHub backend for co-creation. Topic experts prepared the initial material (A), made it accessible through GitHub (B), and compiled the Geo-UAV and Geo-SfM Jupyter Books (C, D). These were subsequently used in Courses 1 and 2, as well as by external users (E), all of whom were invited to provide feedback, suggestions, and to implement revisions (F). Review of the latter was done by both expert (C→A→B) and user groups (G→B), with re-compilation (D) done after final review (C) by a topic expert, before repeating as necessary.

cooperative learning framework. This ~~detailed~~ log of “improvable” sections (e.g., ~~changes in course content~~ course content changes, more accessible phrasing, ~~and~~ additional/revised visual and multimedia assets) was used to ~~further diversify the~~ diversify teaching material and adapt content to ~~the~~ students’ styles and needs~~of the students. As instructors, we held few in-person lectures and were mainly present to facilitate discussions, guide asynchronous learning and provide technical support (Fig. 1).~~ .

Starting in 2024, we ~~offered a more extensive, preparatory~~ introduced a three-hour tutorial on contributing through forks and pull-requests~~following~~ , based on feedback from the 2021 and 2022 courses. These tools allow sophisticated changes to the source code and ~~greatly expand upon~~ expand how contributions can be made ~~, yet~~ but require an extended introduction for optimal use. Each pull-request interaction is documented, attributing co-creators to the revised resource as a form of ownership. ~~We asked students to review each other's proposed revisionsand additions prior to final approval~~ Peer-to-peer evaluation was encouraged for pull-requests and course revisions, though it was not part of the grading process. Final approval of revisions and additions was done by instructors and experts (Fig. 1).

The GitHub platform provided an alternative venue ~~to ask questions and students were encouraged to seek and receive feedback through the platform as well as from instructors. Online (issue) participation on , discussions and physical presentations replaced graded assessments and exams. Classroom teaching further implemented the colloquial sharing of results and experiences during daily recaps in which students presented both their results and stumbles, with feedback and possible solutions mostly provided by other working groups. Peer-to-peer evaluation was also encouraged for pull-requests and revisions suggested to the courses, though were not part of the grading process. The setup of the modules, implementing~~ for questions and feedback from both students and instructors. The modules' setup, with gradual and asynchronous learning, ~~naturally~~ facilitated grading through module completion and participation. Thus, online participation on GitHub, discussions, and physical presentations replaced graded assessments and exams. In Course 2, the shared assessment for ~~the~~ individual sessions was certified and documented in a course certificate, listing the accomplished learning objectives ~~, and stating their equivalent~~and their equivalents.

~~GIFs, given their capacity to capture short animations and generally small file sizes, have become a key communication tool on par with other visual media (Bakhshi et al., 2016; Miltner and Highfield, 2017) and their inclusion has been shown to increase engagement and lower the barriers for participation (Bakhshi et al., 2016). For this reason, we implemented both shorter and longer~~ At the start of both courses, one-week of physical tutoring sessions were scheduled to introduce the modules and content, The sessions mainly involved the sharing of findings and documenting progress in an informal setting led by students. Students presented their results and challenges, with feedback and solutions mostly provided by other groups. We encouraged students to attend the face-to-face tutoring sessions, but they otherwise independently progressed through the modules while working on their term projects during the semester. As instructors, we thus held a few in-person lectures and mainly facilitated discussions, guided asynchronous learning, and provided technical support (Fig. 1).

In module design, we relied on the shared expertise of topical experts, social scientists and students. Topical experts implemented the first versions of the modules, which included short and long animations to supplement videos, ~~detailed~~ plain-language summaries, and static figures ~~in order~~ to improve the accessibility of learning materials. These were then revised through discussions and pedagogical insights, which culminated in the pursuit of involving students in co-creation of educational resources. Input from the UNIS logistics department provided further practical and technical feedback to operational design, which eventually led to the creation of Course 2. Throughout, students were taught how to contribute to the resources, including how to record animations and videos to lower the barrier for co-creating multimedia assets.

GIFs, due to their small file sizes and ability to capture short animations, are key communication tools (Bakhshi et al., 2016; Miltner and I . Their inclusion increases engagement and lowers participation barriers (Bakhshi et al., 2016). We used the LICEcap library (Frankel, 2023) for simple animated screen captures~~because it is a~~ . It is lightweight, intuitive, and ~~flexible application that~~ supports both Windows and OSX~~operating systems. The library supports~~ . LICEcap allows custom capture windows, intermittent recording, and on-screen text messages~~and information. In total,~~ . We incorporated 31 looping animations~~were incorporated with durations of between~~ , ranging from 3.8 ~~and~~ to 78 seconds (Table S2.1). ~~Videos were mainly recorded through the~~

Videos were recorded using Open Broadcaster Studio (OBS) ~~software package (Kristandl, 2021; Bailey et al., 2017). OBS Studio is a freeand~~ (Kristandl, 2021; Bailey et al., 2017), a free, open-source software ~~that is a reliable tool for the recordingof screens, (instructional) videos~~for screen recording, instructional videos, and online streams ~~and is easily used without formal training~~ (Basilaia et al., 2020). OBS ~~Studio~~ supports screen, window, and camera recording with configurable audio~~input and output. In total,~~ . We included 11 videos~~were incorporated with runtime durations of between~~ , ranging from 39 seconds ~~and~~ to 6:28 minutes (Table S2.1). ~~Students were also shown how to use the software, to lower the barrier for co-creation of multi-media assets.~~

During ~~the developmentstages, we particularly~~ development, we appreciated the rich documentation ~~provided by~~ from the Jupyter Book project ~~pages (Executable Books Community, 2020)that offer a detailed tutorial of what is possible with the Jupyter Book framework and provide an extensive~~ (Executable Books Community, 2020). It offers detailed tutorials and a step-by-step guide on ~~how to get started. This easy-to-follow guide further details various options for sharing the dynamic pages, which are optimised for both mobile and desktop use, and even allowed module participants to make more sophisticated changes to the modules. The runtime environment needed to compile the modules can be easily installed using the standard Python package managers pip, conda or mamba, and contains a set of command-line utilities for the compilation of textbooks from Markdown text (. md) , Jupyter~~ using the Jupyter Book framework. We mostly used Markedly Structured Text (MyST) Markdown, given its ease of use, though the framework also supports Notebook (.ipynb) ~~or~~ and reStructuredText (.rst) files~~– all of which open formats. The implementation of the Markedly Structured Text (MyST)~~ . The MyST syntax, an extension of Markdown, provides simplicity ~~while still being powerful enough to create~~ and power for creating rich content pages with text, figures, ~~automatically-generated~~ citations, executable ~~and in-line~~ code-cells, ~~slide-shows~~slideshows, and embedded files (e.g., ~~three-dimensional~~ 3-D ~~, interactive environments) and videos~~interactive environments, videos) (Chen and Asta, 2022; Executable Books Community, 2020). Although not ~~explored~~ used in the Geo-SfM and Geo-UAV modules, pages can ~~also integrate with cloud-providers such as~~ integrate with cloud providers like JupyterHub (Project Jupyter, 2023) and Google Colab (Bisong, 2019) to facilitate executable ~~and programmable content without having to install libraries locally~~content without local library installations.

2.3 Open Pedagogy study

The ~~conducted pedagogy study can be divided into~~ pedagogy study had two phases: the ~~initial~~ design phase and the testing phase. During the design phase of the Geo-SfM module in 2021 and 2022, we collected qualitative data from course evaluations ~~and~~ (to which Geo-SfM was only a module) and through in-class feedback sessions ($n_{2021/2022}$=32). Students' feedback optimized the Geo-SfM module for the following years and informed the design of the Geo-UAV module in early 2023. Starting in 2023, we also ~~implemented~~ used a student questionnaire to gather quantitative and qualitative data on students' experiences and the modules' perceived impact on their learning.

The questionnaire (Table S2.3) focused on the user and learning experience, platform accessibility, multimedia and content diversity, and ~~options for~~ student co-creation options. First, students provided information on their educational backgrounds ~~, and prior-knowledge self-assessments on their programming experience, use of~~ and assessed their prior knowledge of programming, Project Jupyter tools, online documentation, video hosting platforms, and animated GIFs. Second, they answered quantitative (5-point Likert scale; Fig. ~~3~~2) and qualitative (~~Fig. 2~~Table 1) questions about the integrated Jupyter Book and ~~platforms, as well as the integration of multimedia such as~~ GitHub platforms, and the use of multimedia like GIFs and videos ~~.~~ (Fig. 3). The latter specifically addressed different playback durations of ~~the implemented~~ animations and videos to assess student reception and determine optimal playback times versus ~~student~~ self-assessed retention. Qualitative feedback was categorized as either *constructive criticism* or *positive feedback*.

The questionnaire was developed ~~with~~ following the Norwegian National Ethics Committee's Guidelines for Research Ethics in the Social Sciences and Humanities (NESH, 2024)~~in mind. Further, the~~ . The study was internally reviewed ~~through~~ by the University Pedagogy Programme at ~~the University Centre in Svalbard, i.e., the study's host institution. Participation in the survey~~ UNIS. Participation was voluntary, anonymous, and without rewards. The survey was ~~made~~ available through the Jupyter Book modules, and students completed ~~the survey~~ it online via Nettskjema~~. Nettskjema is~~ , an online survey tool ~~developed by~~ from the University of Oslo ~~and is specifically~~ designed to meet Norwegian privacy requirements (Engh and Speyer, 2022). We also collected feedback from external participants who accessed the online modules independently throughout 2023.

~~To grade the openness and accessibility of the two course modules and the Jupyter Book/ framework as a whole, we implemented the *Open Enough* rubric proposed by Christiansen and McNally (2022). McNally and Christiansen (2019) suggest that the openness of OERs can be evaluated through the eight primary factors of openness, being copyright, accessibility, language, support costs, assessment, digital distribution, file format, and cultural considerations, each ranked from "most open" to "closed". However, we evaluated *Harvestability* as a *Technical* rather than *Pedagogical* factor, and based the ranking on a combination of colloquial and questionnaire student feedback, as well as on our own observations as educators and instructors.~~

3 Results

In 2023 and 2024, students participated in the questionnaire during dedicated timeslots immediately after the Geo-SfM module in Course 1 ($n_{2023/2024}$=30) and at the end of Course 2 (n=10). Out of 40 students surveyed, 36 responded. Additionally, four external participants independently responded, resulting in a total of 40 responses. We created the initial coding scheme for qualitative feedback by screening all responses for common themes and understanding levels (Taylor et al., 2015). Table 1 lists the coding scheme and student responses for each category.

Table 1: Qualitative student feedback with descriptions and examples, grouped by category.

Code categories	Code	Description	Example
Accessibility, content and language	Constructive criticism	Responses that criticised the navigation and design of the modules. N=18	Instructions were sometimes not 100 % clear If there would be a search tool, it might be easier to find information on the page. Other languages than English Maybe sometimes background information and instructions are a bit mixed up. Sometimes the background context was lacking, meaning the tutorial was very helpful itself but it required prework that was not explained. Some tricks and tips were not in the Compendium
Accessibility, content and language	Positive feedback	Responses that positively referred to the accessibility, content and language of the modules. N=26	While the tutorial explained exactly what to click it also explained why, which was helpful and gave context. I liked how open and accessible everything was, all the supportive python codes etc., just there to use and make life easier. I really liked how clear and step-by-step the instructions were, as it made it easier to move forward (and go back) in my own pace. The use of alternative/multimedia learning resources makes it inclusive. It is a very useful resource. I will always use it when working with photogrammetry.
Co-creation	Constructive feedback	Responses that independently referred to aspects of co-creation. N=8	It is good that changes can be put in very easy by the user. I liked that it was interactive and that you could change or add anything to improve it for next year. Also, being able to make small changes to the actual site felt inclusive. Some of the instructions used words/names from previous versions of Agisoft, but then again we were encouraged to edit this ourselves (a good thing).
Technical aspects: Navigation and design	Constructive criticism	Responses that critisised the navigation and design of the modules. N=16	Navigation is not intuitive. The flow of the page is not great. Links referring to other compendiums was confusing in the beginning Sometimes a bit too much text and therefore loss of structure.
Technical aspects: Navigation and design	Positive feedback	Responses that positively referred to the navigation and design of the modules. N=28	Flows really well. Clear and logical breakdown of processes and steps are well explained. I liked that the processes had been broken down into bitesize chunks and the exercises were logical to follow.
Technical aspects: Multimedia integration	Constructive criticism	Students were specifically asked about the things they disliked about the use of multimedia in the compendiums. N=30.	In some of the videos the text was so zoomed out that it was hard to see what exactly what was being done. Videos were too slow Sometimes not text to describe the step, only GIF. Provide text alongside animations/videos. Not able to pause GIFs. GIFs do not have a clear start/end Some GIFs were a bit too long, so if you missed something in the beginning you had to re watch
Technical aspects: Multimedia integration	Positive feedback	Students were specifically asked about the things they liked about the use of multimedia in the compendiums. N=39.	The use of videos throughout and along with the instructions was good. Provide quick overview. Made things easy to follow, findable in menus. GIFs are short and therefore show the information very effectively. I did not watch as many YouTube videos but they can show more complex things. As I am a visual learner, the animated GIFs helped me a lot throughout the week as it helped to navigated what needed to be done.

The quantitative results are shown as stacked box-plot charts for either module (Fig. 2, Fig. 3)~~, with examples~~. Examples of student responses from open-ended questions included in the results and discussion. The analysis does not distinguish between internal and external evaluations, nor does it separate results by course.

3.1 Student perceptions on the learning environment

Student perceptions of the Geo-SfM and Geo-UAV modules were measured using Likert-scale questions developed specifically for this study~~, with feedback largely similar between the two~~. Feedback was largely similar for both modules. Overall, students ~~agreed that they~~ were excited about using the online modules, ~~that~~ felt the modules met their needs, and ~~that the content was~~

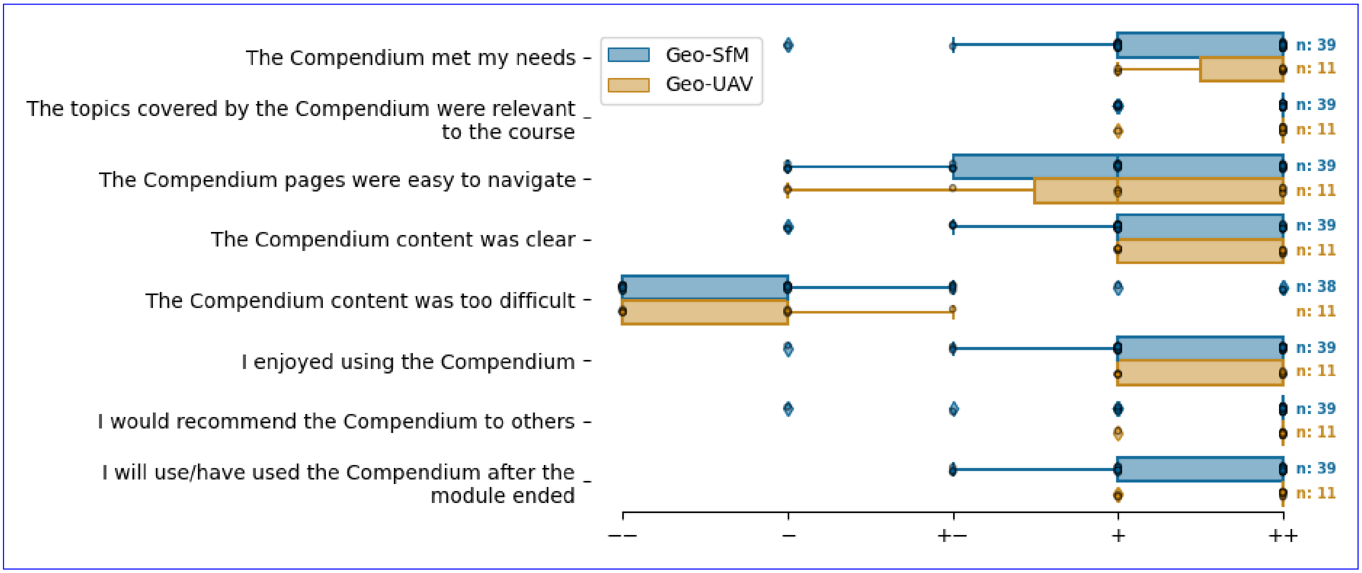

Figure 2. Quantitative student feedback on the Geo-SfM and Geo-UAV modules, here referred to as Compendiums. The bars, boxes and whiskers indicate the mean, one standard deviation and two standard deviations, respectively. Individual scores are separated for clarity.

found the content clear and easy to navigate. Students also indicated they would recommend the modules to others and use them as reference works in the future (Fig. 2).

Answers to the open-ended questions (e.g., Table 1) reflected a positive learning experience. Students valued the Jupyter Book/GitHub implementation for its modernness and clear structure, despite few having had prior familiarity with it or other documentation platforms like it similar documentation platforms (Fig. S2.1). They also appreciated the platform's open online nature, which was mentioned to facilitate diverse and asynchronous learning at their own pace.

Students praised the Geo-UAV module for providing a "very good overview of a complex topics and integration of different sources" and "liked how open accessible everything was". They appreciated "that the processes had been broken down into bitesize chunks and the exercises were logical to follow". One student even referred to the modules "as a 'bible' of tutorials throughout the course", while another noted that the platform helped "consolidate a large amount of information that, if it had purely been communicated verbally, would have been overwhelming to absorb".

Similar reflections were obtained for the Geo-SfM module. Students noted that "all the supportive Python codes etc., [are] just there to use and make life easier" and "liked that pictures and GIFs were used in the tutorials", though not all students were equally excited about lengthy animations.

3.2 Student perceptions on integrated multimedia use

As instructors, we had aimed to create a diverse and accessible learning environment through use of multimedia integration and student-led content creation. Thus, students Students were specifically asked about their previous experiences with multimedia (Fig. S2.1) and how they perceived the use of GIFs, videos, and interactive content in the modules.

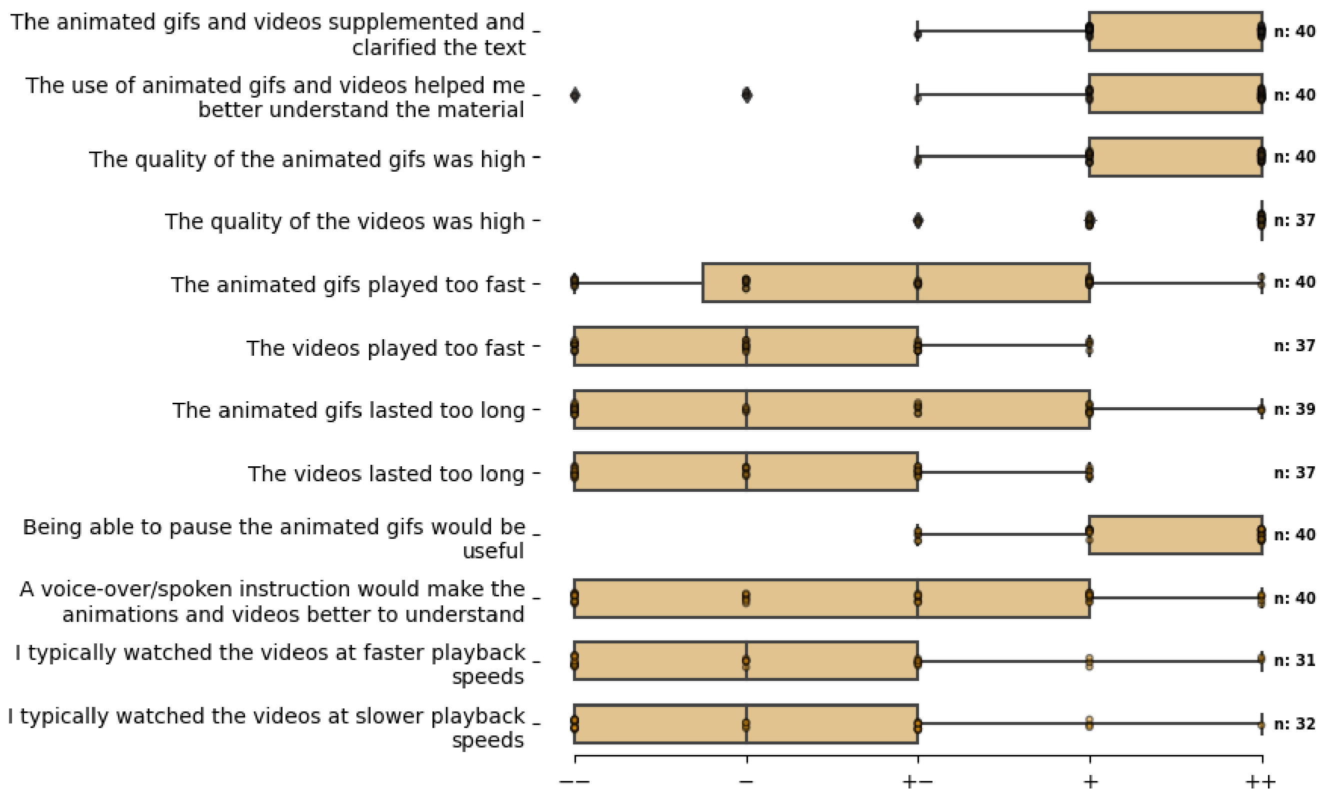

Figure 3. Student feedback on how well they experienced the inclusion of animations and video assets. The bars, boxes and whiskers indicate the mean, one standard deviation and two standard deviations, respectively. Individual scores are separated for clarity.

~~Students~~ In response, students highlighted the benefits of animations and videos alongside text descriptions, noting these elements enhanced course content diversity and accessibility. Their open-ended remarks (Table 1) on the use of animations and videos ~~within the modules~~ aligned with their quantitative feedback (Fig. 3). They agreed that animations and videos effectively supplemented the main text ~~effectively~~ and were of high quality. However, students found the playtime of multi-step animations (i.e., GIFs) too long and suggested a pause function (Fig. 3). Open-ended responses indicated frustration with waiting for GIF loops to end and ~~the need~~ needing to replay them multiple times to understand all steps ~~, as shown in student-reported playtime statistics~~ (Table S2.2). Examples include ~~that they did not like having~~ not liking “to wait for the loop to end to see again the info [they] wanted to see” and ~~that they “had~~ having “to play it [GIFs] several times to identify all steps”. Despite this, students found GIFs useful for illustrating processes and reducing reading.

3.3 Student perceptions on co-creation possibilities

Although we did not quantitatively assess student perception on co-creationwas not quantitatively assessed, eight students independently reflected on it through the open-ended survey questions. Students They noted that “being able to contribute to it [the modules]” and “also see other’s contributions was helpful in filling in gaps”.

Students actively enhanced the modules by extending functionality, improving clarity, and updating animations and figures (Fig. S2.2). This is evidenced by 39 pull requests to the Geo-SfM module by 10 students from the 2024 class, who benefited from an extended introduction to . Contributions varied from single-word edits to multi-paragraph revisions and new animations.

Unsurprisingly, a subset of students in prior years reported agreement that they were “a bit confused … when it came to using ” as [knowledge] gaps” in co-creating resources. Unsurprisingly, some students from previous years reported confusion when using GitHub through classroom feedback, suggesting they were not fully introduced to the platform’s possibilities at the onset of the courses. The differing levels of introduction, however, did not change student-reported However, this did not affect their sense of inclusiveness in content creations, creation or their overall learning experience. Both cohorts reported that it felt felt it was inclusive to learn from student-proposed changes from previous years and to be able to further revise and improve the previous student contributions and to improve resources for future use, thus becoming part of the community. The “use of GitHub/git to enable community contributions” was noted as an important a key factor that set the modules apart from previous learning experiences.

Both Geo-UAV and Overall, students improved the modules by extending functionality, clarifying content, and updating animations and figures (Fig. S2.2). This is shown by 39 pull requests to the Geo-SfM (and the Jupyter Book/ framework as a whole; Table ??)rank high on openness within the *Open Enough* rubric, outranking many of those rated by Christiansen and McNally (2022) . Key contributions are the modules’ learner-centred design and the implementation of collaborative and inclusive design choices in a modern, open format. The few *Mixed* and ratings are a result of design choices, such as the use of expensive UAVs and sole implementation of the English language. module by 10 students from the 2024 class, who benefited from an extended introduction to GitHub. Contributions ranged from single-word edits to multi-paragraph revisions and new animations.

Openness as evaluated against the *Open Enough* considerations outlined by Christiansen and McNally (2022), treating *Harvestability* as a *Technical* rather than *Pedagogical* factor.Course Module Copyright/OL Discoverability File Format Harvestability Geo-UAV Mixed (CC-By-NC) Most Open Most Open Most Open Geo-SfM Mixed (CC-By-NC) Most Open Most Open Most Open Language Material costs Assessment Accessibility Geo-UAV Closed Mixed Mixed Most Open Geo-SfM Closed Mixed Mixed Most Open Diverse users Culturally inclusive Easy to navigate Responsive design Geo-UAV Yes Yes Yes Yes Geo-SfM Yes Yes Yes Yes

4 Discussion

During the first stages of module design, we as instructors had deemed the Jupyter Book/GitHub framework an ideal starting point for the creation of cocreated resources, given how easily it facilitates collaboration and integration of interactive content, and that it can easily be tailored to specific needs. Openness and interactivity ~~drives~~ drive engagement, interest, and exploration of concepts, which ~~is crucial to both~~ are crucial for learning and scientific thinking. ~~Both~~ Geo-UAV and Geo-SfM were designed with ~~that~~ this in mind, ~~and both were tailored bottom-up~~ tailored to support courses ~~where students have a wide range of~~ with students of varying experiences and abilities. ~~Jupyter Books are naturally suited for such an environment. The framework provides a way to integrate~~ The modules were also designed to present content in a variety of formats, integrating extensive narrative content with examples, videos, animations and code templates for those ~~in need of support, while more-experienced students can modify and adapt examples to independently explore more advanced scenarios~~needing support.

~~Simultaneously building~~ Building comprehensive teaching materials and designing pedagogical feedback processes ~~, however, can be a challengingtask, and one that can only be accomplished through an~~ is challenging, yet can be eased through interdisciplinary collaboration between natural and physical scientists, social scientists, and students. ~~Over these past four years, we learned that~~ For example, we experienced that once topic-experts had created the basic modules, more experienced students could modify and adapt examples to explore advanced scenarios independently. If encouraged to do so, they were then likely to contribute to the modules, providing the resources for the remainder of class to follow. Social scientists had a key role herein, providing guidance and feedback on how to facilitate and optimise this collaboration. This was a key take-away from the iterative development of the modules and courses ~~, as well as from designing the pedagogies~~ over the past four years, and certainly aided the design of the pedagogical framework itself. ~~Initially, the focus was~~

Initially, we focused on assessing the technical usability of the modules and ~~assessing the usability of the~~ the Jupyter Book framework~~for its learning-potential, including the role of integrating~~ 's learning potential, including multimedia and animations~~therein. In years 3 and 4, qualitative student reflections highlighted the potential for~~ , through in-class discussions and classroom feedback. We quickly realised a need to quantify findings, which supplemented in-class discussions with qualitative and quantitative student reflections on co-creation and the inclusivity, diversity, and accessibility ~~benefits~~ potential of the Jupyter Book/~~framework. These insights lay the groundwork for future activities to quantify student perceptions of these aspects. Our results provide~~ GitHub framework. The feedback we received provides a starting point and valuable ~~insight into designing and co-creating~~ insights into the design and co-creation future OER-P content using modern educational platforms.

Overall, students perceived the Jupyter Book format and modules as useful for supporting their learning, ~~while also expressing~~ though they had some concerns about ~~some of the~~ certain design choices. Many of these concerns have been systematically addressed during the ~~4-year runtime of the project, in part~~ four-year project, partly through student contributions ~~, in part~~ and partly through social science insights.

In the ~~discussion that follows~~following discussion, we integrated ~~the~~ students' survey responses with our ~~own~~ observations to evaluate the modules' ~~relative openness/accessibility~~openness, accessibility, and other pedagogical factors~~by implementing an *Open Enough* rubric (Christiansen and McNally, 2022). We did so to address the objectives raised in the introduction , as well as to aid our understanding of how~~ . This addresses the objectives from the introduction and helps us understand how students view the Jupyter Book framework ~~is viewed by students and how it can be implemented as a means of~~ and its potential for co-creative open learning.

4.1 Learner-centred design - Co-creating accessible and diverse resources

Open-source curricula ~~have been shown to facilitate~~ encourage participation, discussion, and co-ownership ~~amongst~~ among students and the broader community, inviting ~~all to participate in the collaborative development of~~ everyone to collaborate on educational resources (Chen and Asta, 2022; Kim et al., 2021) ~~. Analysis of colloquial and quantitative questionnaire~~ Student feedback (Table 1) ~~provided by the students indicated as much and~~ highlighted several advantages of ~~using~~ the Jupyter Book/~~framework, in particular. First, the interactivity of the modules, exposure to pre-written code (snippets), and integrated multimedia use~~ GitHub framework:

- **Learning effectiveness**: Step-by-step instructions and information in various formats and levels of interactivity were highly effective and provided a rich ~~and diverse learning experiencecertainly helped demystify the abstract notions of scientific data acquisition and processing. Second, we noticed that the availability of co-creation examples from previous years to learn from, as well as being introduced to the unformatted source code of the teaching resources lowered the barrier for students to become contributors. Third, students noted the learning effectiveness of the modules, in particular the usability of step-by-step instructions that were provided in various formats, different voices, and different levels of interactivity. Fourth, students affirmed what we had hypothesised – that for students to become contributors, they first~~ learning experience. This improved independent student learning and elevated the role of instructors to tutor.

- **Co-creation**: Students are eager to contribute. However, students need to be comfortable ~~using~~ with the tools and ~~be given ample opportunity and freedom~~ have opportunities to revise content, with ~~the side note that it is reviewed and fact-checked by other students and course instructors prior to implementation. The latter, however, must not stand in the way of students to think about what else can be built into the tool to support their learning and that of others. Indeed, students agreed that the exposure to code, programming and the~~ peer and instructor review ensuring quality.

- **Learning from others**: Examples from previous years and access to unformatted source code lowered the barrier for contributions, starting a cycle of learning from others.

- **Scientific problem-solving**: Students agreed that exposure to the source code and documentation backend was beneficial~~to the learning experience (Tab. 1), which may in part be because~~ , as creating cohesive content ~~follows aspects of (scientific) problem solving:~~ involves scientific problem-solving skills, which, as summarised by Barba et al. (2019), include Decomposition, Pattern ~~recognition~~Recognition, Abstraction, and Algorithm ~~design (Barba et al., 2019).~~ Design.

Given that the modules are openly available on the internet and provide accessibility by supplementing multimedia and ~~user-interactions~~user interactions, it is not surprising that the students rated the Geo-UAV and Geo-SfM modules favourably in terms of accessibility. ~~After all, a simple search-engine search for *structure from motion photogrammetry tutorial* at the time of submission~~ A web search for "structure from motion photogrammetry tutorial" shows the Geo-SfM module among the ~~top-listed results , and underlines the accessibility factor of the modules in in the practical sense. So too, do the external contributions to both Geo-UAV and Geo-SfM, and the~~ top results in all top search engines, highlighting its practical accessibility.

External contributions and feedback from four external participants ~~that independently provided valuable survey feedback to the modules . Both modules also rated positively on~~ also support this. In addition, the modules received positive ratings for clarity, ease of use, ~~diversity of content , and their modern design, though would benefit from being translated into additional languages (improving upon the modules' current *Closed* language rating in the *Open Enough* rubric, Table **??**).~~

content diversity, and modern design. Indeed, some ~~of the~~ technologies and software ~~being used~~ were unfamiliar to ~~the students, though this was easily~~ students, but this was overcome through active facilitation, ~~concise~~ foundational work, and hands-on guidance by instructors. For example, ~~the introduction to the backend , alongside~~ introducing the GitHub backend and providing a brief tutorial on ~~how to revise the~~ revising Jupyter Book files ~~, in particular, cultivated an interest in revising the source materialsand update information where it was deemed outdated or inconclusive - a recurring student feedback theme~~ sparked interest in updating source materials, which was a recurring theme in student feedback (Table 1). ~~Students easily~~ Other aspects remain a work in progress, including access to translated modules. With few of the instructors having the resources to maintain the content in the various languages spoken by the students, this remains an important yet unaccomplished milestone. Luckily, the Jupyter Book/GitHub framework allows students and other contributors to contribute and integrate translations, which leads to shared responsibility, ownership and enhanced accessibility through co-creation.

Students' attitudes to co-creation are best exemplified by the ease with which students identified and raised issues, which were then curated and patched by themselves and others~~, who then also became contributorsand~~ . Through this, students not only became contributors, but also co-owners of the content. ~~In addition, the collaborative experience resulted in enhanced collaboration, where multiple student pairs worked together to put more extensive revisionstogether~~The collaborative experience enhanced teamwork, with student pairs working together on extensive revisions, including multimedia (e.g., Fig. S2.2). ~~Students described the practice as increasing their feeling~~ Co-creation also heightened the sense of belonging, with one student ~~reflecting~~ noting that the ability "to make small changes to the actual site felt inclusive"~~and another mentioning the benefits of seeing student~~ , and another student appreciating contributions from past years. ~~Co-creation also~~ Overall, co-creation led to pedagogic improvements~~in the resources. Through student-led revisions,~~ , making the language and content ~~became~~ clearer and better aligned with students' perspectives and ~~level of~~ understanding.

4.2 Design choices - lessons learned and future directions

~~The iterative and open development of educational content demands considerable effort to create~~ Creating an initial environment ~~that is suitable~~ for students to contribute to ~~. This workload is , however, not unlike the creation of other course content such as lecture slides, and, once established, the OERs benefit inherently from remaining~~ educational content requires considerable upfront effort. However, this workload is similar to creating other course materials like lecture slides. Once established, OERs remain accessible and adaptable to future needs~~with only minimal time required~~ , requiring minimal time for student-led ~~(decentralised /co-created) revisions .~~

~~Indeed, it is encouraging to see~~ and decentralised revisions on the condition that setup and maintenance are straightforward, and softwares easy to use. It is thus encouraging that off-the-shelf software and infrastructure now allow for the easy creation, curation, sharing, adaptation, and use of open-source curricula (e.g., Chen and Asta, 2022; Kim et al., 2021; Executable Books

Community, 2020). Using Jupyter Book/~~, changes in course content~~ GitHub, course content changes can be easily tracked and reintegrated ~~where applicable~~ with the source or ~~form the~~ used as a starting point for ~~derived~~ new educational content, contributing to ~~the~~ community-driven ~~development of OERs that makes learning more accessible~~ OER development (e.g., Kim et al., 2021). This was particularly useful in ~~the development of~~ developing Course 2, as we ~~were able to build upon~~ could build on the Geo-SfM module's history tracking and transfer previously removed side-notes on data acquisition to the ~~more appropriate~~ Geo-UAV module. Version control ~~further allows the documentation of changes, and~~ documents changes, allowing instructors and students ~~alike can easily visualise changes made to the modules over time , and even~~ to visualize changes over time and reinstate previously removed content. ~~Version control also aids in the mitigation of knowledge loss~~ It also helps mitigate loss of knowledge due to e.g. ~~turn-over of faculty staff~~faculty turnover, loss of licenses, or sudden machine failure.

~~Both the developmental use of such tools , as well as raising awareness of what can be done with them benefits from dedicated tutoring . This was highlighted by students requesting specific feature, such as implementing a~~ Even off-the-shelf tools need dedicated tutoring for optimal use. For example, students often missed native Jupyter Book features such as the search bar, ~~even though search is natively included in the Jupyter Book menubar and students frequently used the menubar in teaching. Other examples include requests on where and how to find educational resources online, which may benefit from having curated (and searchable) portals for thematic content hosted by the community. As a word of caution, student feedback mentioned incoherent~~ and they found extensive cross-linking between ~~different modulesas a point of confusion~~ modules, especially in Course 2, confusing (Table 1)~~in Course 2, as it was not entirely clear to them which of the two modules required their focus at a given time. We thus note that students benefit from extended~~ . Thus, introductions to the Jupyter Book interface~~and backend, even for seemingly obvious functions, as well as from a clear introduction to the structure of the modules at the beginning of a course~~, GitHub backend, and module structure were deemed essential, and we started providing more extensive introductions at the start of the courses from year 2. The introduction to GitHub was particularly important, as students needed to be comfortable with the platform to contribute effectively.

With regards to field teaching, Geo-UAV showcased the benefits of having interactive and portable documentation that can be easily exported and integrated into field-based teaching. Given our and our students' experiences, we are currently developing additional modules that target field instruments (e.g., differential positioning and various geophysical imaging tools) to further investigate the framework's suitability in field teaching. The development (and future implementation) of these modules largely builds upon the key ~~take-aways~~ takeaways presented in this study, itemised in Appendix S1. ~~These will also try and find *Open* rather than *Mixed* solutions for the *Open Enough* rubric's *Material costs* and *Assessment* factors. Both are currently *Mixed* due to respectively the use of closed-source softwares and tools (e.g., drones) and the current lack of *Open* forms of assessments that can be taken beyond the classroom activities. This is in part due to the topics covered by Geo-UAV and Geo-SfM and current design choices of the modules, rather than stemming from Jupyter Book framework limitations.~~

4.3 The teachers' perspective

From a teacher's perspective, a key objective of the digital compendiums was to provide lasting, up-to-date course material ~~to a campus with a small department that does not have significant experience nor capacity~~ for a small department with limited experience in developing and maintaining OERs. Another important objective was to create an interactive environment that promotes active learning (Barba et al., 2019; Freeman et al., 2014) and facilitates learning at one's own pace and interest, which are ~~key to~~ crucial for learner-centred and asynchronous learning (Georgiadou and Siakas, 2006). ~~Herein the~~

The use of GIFs ~~certainly took~~ played an important role ~~.~~

in accomplishing both objectives. GIFs provided visual~~and stepwise instructions that greatly simplified otherwise abstract instructions~~, step-by-step instructions that simplified abstract concepts, supplementing the narrative text with easy-to-follow graphics. ~~In addition to their stated learning values, it certainly helped that GIFs can be easily made at~~ They are easy to create, have low file sizes, and feature a low participation barrier for co-creation, as ~~evident from pull requests by students~~ shown by student pull requests (Fig. S2.2). The format ~~lends itself exceptionally well~~ is excellent for short visual instructions, ~~yet can be easily "overdone" in terms of informationdensity. In case of the latter, we noticed an increase in questions at the cost of independent learning while~~ often replacing the need for a physical instructor. However, GIFs can certainly be overloaded with too much information. This can lead to more questions and less independent learning in class, highlighting the ~~fine balancein its implementation~~need for balance. Further research is ~~thus~~ needed to optimize GIF content for teaching, ~~as previously done for videos (e.g., Guo et al., 2014)~~similar to previous studies on videos (e.g., Guo et al., 2014).

With students ~~actively~~ co-creating and maintaining learning and multimedia resources, we ~~experienced~~ saw a significant drop in preparatory workload~~and instead enabled work~~. This allowed us to focus on more in-depth resources and specific content requested by students ~~. We also observed that this shifted lectures~~ during their asynchronous learning. The modules thus shifted from a teacher-centric to a learner-centric model~~that revolved~~, centred around student-led discussions of findings and design choices. ~~Both aspects simultaneously~~ This freed up time ~~and allowed~~ for instructors to step in ~~only when really needed. As noted from a student's remark, this was greatly appreciated and provided~~ when needed. Students appreciated this approach, feeling a unique sense of ~~inclusivity and resulted in~~ inclusiveness and benefiting from a hands-on ~~approach that lectures on a similar topic elsewhere had lacked. The asynchronous and hybrid nature of the modules thus seems to have lowered the participation barrier which may also benefit non-traditional learners and students from underrepresented groups who may have less initial experience with either of the topics covered by the modules.~~ experience that other courses and lectures lacked.

5 Conclusion

This study designed and explored students' attitudes towards educational Jupyter Books hosted on the GitHub platform. In summary, Jupyter Book modules can be easily created, shared, adapted, remixed, and, importantly, are very user friendly. Quantitative survey responses indicated a positive student perception to the learner-centric learning environment as well as the co-creation possibilities provided by the Jupyter Book/GitHub framework. The interactive multimedia environment was positively experienced by the students and facilitated asynchronous and active learning. It drove engagement, interest, and exploration of concepts that ~~benefitted both~~ benefited students' learning and scientific thinking. GIFs were also seen as a positive addition, yet work remains to establish optimal playtime durations. The collaborative nature of the modules was instrumental in cultivating an interest in revising the source materials and updating information where it was deemed outdated or unclear, both by students and instructors alike, and regardless of the contributor's background, affiliation or level of experience. We found that co-creation can decrease the workload to maintain and expand up-to-date course content, thus accomplishing one of our key objectives: to provide lasting, up-to-date course material to a campus with a small department that does not have significant experience nor capacity in developing and maintaining OERs. We also found that Project Jupyter tools can be easily adapted to create a learning environment more suitable for co-creation, requiring only minimal former programming experience. These findings, along with students' positive assessment of the Jupyter Book framework's inclusivity, diversity, and accessibility, ~~contribute to the *mostly open* ranking both modules attained within the *Open Enough* framework of ranking open pedagogies openness~~emphasise the benefits of using the framework in teaching.

In closing, we hope that by documenting our approach to co-creating OER-P content, we have set an important step in a community-wide effort to catalogue, develop and co-create educational content, and make these openly available and findable to users. ~~However, such an effort can only succeed through~~ Such an effort certainly benefits from an interdisciplinary approach in which natural and physical scientists, social scientists, and students co-create ~~teaching resourcesand assess course design and learning~~ educational resources, improve course designs, and learn in parallel.

Data availability. The source material for the Geo-UAV and Geo-SfM modules, as well as that of Geo-MOD (Course 2) is freely available from their respective Zenodo repositories, available alongside URLs to the compiled books in Table 2.

Table 2: Data availability of the modules, including URL references.

Module	URL	Reference
Geo-MOD	https://unisvalbard.github.io/Geo-MOD	Betlem et al. (2024)
Geo-UAV	https://unisvalbard.github.io/Geo-UAV	Rodes et al. (2024)
Geo-SfM	https://unisvalbard.github.io/Geo-SfM	Betlem and Rodes (2024)

Author contributions. PB: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Writing & Reviewing, Visualization, Project administration, Funding acquisition, Project administration. NR: Methodology, Software, Investigation, Resources, Writing – Writing & Reviewing, Visualization, Funding acquisition, Project administration. SMC: Resources, Writing – Writing & Reviewing, Funding acquisition, Project administration. MVK: Conceptualization, Methodology, Writing – Original Draft, Writing – Writing & Reviewing, Supervision.

Competing interests. The authors declare that they have no conflict of interest.

Ethical statement. The data used in this study were collected on a voluntary and anonymous basis. Identification of individual participants in the questionnaire is impossible. The questionnaire was developed with the Norwegian National Ethics Committee's Guidelines for Research Ethics in the Social Sciences and Humanities in mind. Further, the project was internally reviewed through the University Pedagogy Programme at the University Centre in Svalbard (UNIS), i.e., the host institution.

Acknowledgements. Foremost, we thank the participating students for constructive feedback and their eagerness to participate in and co-create the modules. We also thank UNIS colleagues Kim Senger, Aleksandra Smyrak-Sikora, Rafael Horota, and Thomas Birchall for feedback during the first years of implementation. We also acknowledge funding and support from the Norwegian Centre for Integrated Earth Science Education iEarth (Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education grant #101060) and additional funding provided by the Norwegian CCS Research Centre (NCCS; industry and partners and the Research Council of Norway grant #257579). Similarly, we keenly acknowledge the close collaboration with the Svalbox project (co-financed by the University of the Arctic, the Research Council of Norway and the University Centre in Svalbard). We appreciate the academic licenses of Metashape provided by Agisoft, as well as the UAVs and other hardware made available through the Svalbox project. We also thank Henrikki Tenkanen and Vuokko Heikinheimo and their Automating GIS-processes documentation for introducing us to the world of Jupyter (educational) Books and open course documentation. Finally, we sincerely appreciate the constructive discussion with reviewers Enze Chen and Jonathan W. Rheinlænder, as well as the excellent editorial handling and constructive feedback by Mathew Stiller-Reeve.

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Supplementary Material S1: Do's and don'ts for implementing the Jupyter Book/GitHub framework

The below provides a brief cheat-sheet for implementing Jupyter Book/GitHub as a teaching platform, mostly targeting narrative content and summarising some of our key experiences and learnings.

- **Read and share the docs**: The Executable Books (Executable Books Community, 2020) project provides extensive documentation for both Jupyter Book and the MyST Markdown language used to write the books. The documentation includes a start-up guide, as well as easy-to-follow topic guides written in simple language. Do not forget to share this with your students for inspiration.
- **Create a minimal working book**: Generate an outline of the to-be-covered topics and create a separate chapter (i.e., one or multiple files) for each and populate the chapter pages with the minimum educational material that needs to be covered in class.
- **Keep it simple**: Going back and forth between different sections (and modules), was shown to confuse students, as was the (attempted) inclusion of too many topics at once. First, try to avoid extensive cross-linking between pages and content blocks and instead design the module to follow a single red thread. Second, rather create supplementary books covering related topics than including too much content at once.
- **Provide examples**: Both narrative and multimedia content should be included in the minimal working book, as well as computational content when applicable. The overlapping multimedia approach provides diverse and asynchronous learning options, in addition to providing a quick lookup sheet for student to adapt source-code snippets from during co-creation.
- **Familiarise students with the framework**: Do not expect students to create content out of thin air. First, students need to be comfortable using the tools and be given ample opportunity and freedom to revise content. This means one must first lay the foundation for co-creation. For example, start with the basics by explaining students how to navigate the Jupyter Book pages, provide a basic introduction on how to use the GitHub backend. A simple "hello world" post on GitHub is an easy start. Then extend their co-creation skills by introducing more extensive revisions through forks and pull requests, for example asking students to fix spelling mistakes or replace a figure. Another example, taken from the Geo-SfM module, is to ask students to share their results by updating a built-in gallery, in Geo-SfM done by pull-requesting a model tag into a configuration file on the "Uploaded examples" page. Remember, for those without a programming background, such a revision may already feel like extensive programming and quite the achievement.
- **Co-creation over time**: Do not expect pages worth of content to be added by students at once, rather, the minimal working book will evolve over time as revisions and additions culminate in a compendium co-shaped by students.
- **Encourage additions and revisions**: Faster-paced students, those who have taken similar courses elsewhere, or those interested in more advanced scenarios may be eager to extend the course content. This is best done by giving them a well-defined task, which can be as simple as asking them to e.g., document (both text and GIFs) what function X does in program Y or to expand a pre-existing section.

- **Usability vs. functionality**: Use open and/or pre-installed softwares, such as the snipping tool, that are easy to use by both instructors and students alike, rather than overly-complex softwares and tools. These typically make for straightforward tools that capture content in sufficient quality to be included in the course while being time- and resource-efficient.
- **Keep it concise**: Describe things stepwise and to the point. Try to include only one step per accompanying GIF at a time, opting rather for several than for one long animation.
- **Learning first and foremost**: The students' main focus should be on ~~absorbing~~ engaging with and shaping course content, and not on dealing with compilation errors and software bugs. Thus, it is highly advised that instructors maintain control over the "build" process of the Jupyter Book pages. This also allows instructors to inspect changes prior to publishing. Secondly, it is advised to only sporadically re-build the books from their source, ideally when students are not using the resource. This to prevent confusion due to e.g. mismatching pages and unexpected changes.
- **Disseminate**: The open sharing and listing of Jupyter Books (for example in the Jupyter Book Gallery) helps others find, access, integrate and reuse their resources. External collaborators may even contribute to the Jupyter Book, supporting co-creation and collaboration within the greater community.

Supplementary Material S2: Supplementary Tables and Figures

Table S2.1: Multimedia counts and playtime statistics.

Module	Feature type	Feature count	Internal/External	Playtime (min)	Playtime (mean)	Playtime (max)	Playtime (std)
Geo-SfM	Animated GIFs	17	17/0	8.4 s	23.7 s	78.0 s	17.9 s
Geo-UAV	Animated GIFs	14	14/0	3.8 s	8.1 s	13.0 s	2.3 s
Geo-SfM	Video	4	1/3	130 s	171.8 s	206 s	32.9 s
Geo-UAV	Video	8	2/6	39 s	178.6 s	388 s	101.4 s

Table S2.2: Feedback on the average number of times an animation or video was replayed and paused.

Frequency	Ani. rewatch	Vid. rewatch	Vid. pause
0	6	18	18
1-3	21	23	17
4-6	12	0	4
7-10	2	0	2

Table S2.3: Questions and answer options.

Question/statement	Answers	Ref.
BACKGROUND INFORMATION		
I am affiliated/enrolled with UNIS...	YES | NO	
My (educational/scientific) background mostly corresponds to....Biology	YES | NO	
My (educational/scientific) background mostly corresponds to....Geology	YES | NO	
My (educational/scientific) background mostly corresponds to....Geophysics	YES | NO	
My (educational/scientific) background mostly corresponds to....Technology	YES | NO	
My (educational/scientific) background mostly corresponds to....Safety	YES | NO	
My (educational/scientific) background mostly corresponds to....Guiding	YES | NO	
My (educational/scientific) background mostly corresponds to....Other	YES | NO	
BACKGROUND KNOWLEDGE		
I was familiar with programming (e.g., Python, R, matlab)	– | - | -+ | + | ++	Fig. S2.1
I was familiar with Jupyter Notebook/Lab	– | - | -+ | + | ++	Fig. S2.1
I was familiar with Jupyter Book/Executable Book Project/Sphinx/Read The Docs	– | - | -+ | + | ++	Fig. S2.1
I was familiar with YouTube	– | - | -+ | + | ++	Fig. S2.1
I was familiar with animated GIFs	– | - | -+ | + | ++	Fig. S2.1
I was familiar with git (e.g., GitHub)	– | - | -+ | + | ++	Fig. S2.1
DEVICE USED		
I used the following device to read/interact with the compendiums:.Mobile phone	YES | NO	
I used the following device to read/interact with the compendiums:.Tablet	YES | NO	
I used the following device to read/interact with the compendiums:.Desktop	YES | NO	
RATINGS AND OBJECTIVES		
What were your (learning) objectives when following the XXX Compendium?	Open	
Future documentations - your compendium ideas?	Open	
Rate your overall experience of using the XXX Compendium on a scale from 0 to 10, with 0 being extremely dissatisfied and 10 being extremely satisfied.	0 to 10	
Rate your overall experience of learning with the XXX Compendium on a scale from 0 to 10, with 0 being extremely dissatisfied and 10 being extremely satisfied.	0 to 10	
COMPENDIUM INFORMATION		
The XXX Compendium met my needs	– | - | -+ | + | ++	Fig 2
The topics covered by the XXX Compendium were relevant to the course	– | - | -+ | + | ++	Fig 2
The XXX Compendium pages were easy to navigate	– | - | -+ | + | ++	Fig 2
The XXX Compendium content was clear	– | - | -+ | + | ++	Fig 2
The XXX Compendium content was too difficult	– | - | -+ | + | ++	Fig 2
I enjoyed using the XXX Compendium	– | - | -+ | + | ++	Fig 2
I would recommend the XXX Compendium to others	– | - | -+ | + | ++	Fig 2
I will use/have used the XXX Compendium after the module ended	– | - | -+ | + | ++	Fig 2
What did you like most about the XXX Compendium? Try to come up with at least two examples.	Open	Table 1
What did you like least about the XXX Compendium? Try to come up with at least two examples.	Open	Table 1
MULTIMEDIA QUESTIONS	– | - | -+ | + | ++	Fig. 3
The animated GIFs and videos explained the content clearly	– | - | -+ | + | ++	Fig. 3
The animated GIFs and videos supplemented and clarified the text	– | - | -+ | + | ++	Fig. 3

continued . . .

…continued

<table>
<tr><th>Question/statement</th><th>Answers</th><th>Ref.</th></tr>
<tr><td>The use of animated GIFs and videos helped me better understand the material</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>The quality of the animated GIFs was high</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>The quality of the videos was high</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>The animated GIFs played too fast</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>The videos played too fast</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>The animated GIFs lasted too long</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>The videos lasted too long</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>Being able to pause the animated GIFs would be useful</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>A voice-over/spoken instruction would make the animations and videos better to understand</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>I typically watched the videos at faster playback speeds</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>I typically watched the videos at slower playback speeds</td><td>– | - | -+ | + | ++</td><td>Fig. 3</td></tr>
<tr><td>On average, I rewatched individual animated GIFs x times</td><td>0 | 1 - 3 | 4 - 6 | 7 - 10</td><td>Table S2.2</td></tr>
<tr><td>On average, I rewatched individual YouTube videos x times</td><td>0 | 1 - 3 | 4 - 6 | 7 - 10</td><td>Table S2.2</td></tr>
<tr><td>On average, I paused YouTube videos x times</td><td>0 | 1 - 3 | 4 - 6 | 7 - 10</td><td>Table S2.2</td></tr>
<tr><td>What did you like about the mixed use of animated GIFs and videos in the compendiums? What worked?</td><td>Open</td><td>Table 1</td></tr>
<tr><td>What did you dislike about the mixed use of animated GIFs and videos in the compendiums? What did not work?</td><td>Open</td><td>Table 1</td></tr>
<tr><td>DID YOU KNOW?</td><td></td><td></td></tr>
<tr><td>Individual compendium pages can be generated as PDFs from within the pages themselves?</td><td>YES | NO</td><td></td></tr>
<tr><td>You can contribute and suggest changes directly from the compendium pages?</td><td>YES | NO</td><td></td></tr>
<tr><td>The raw material for each compendium is openly available on GitHub?</td><td>YES | NO</td><td></td></tr>
<tr><td>GitHub hosts an issue and bug tracker for each of the compendiums?</td><td>YES | NO</td><td></td></tr>
</table>

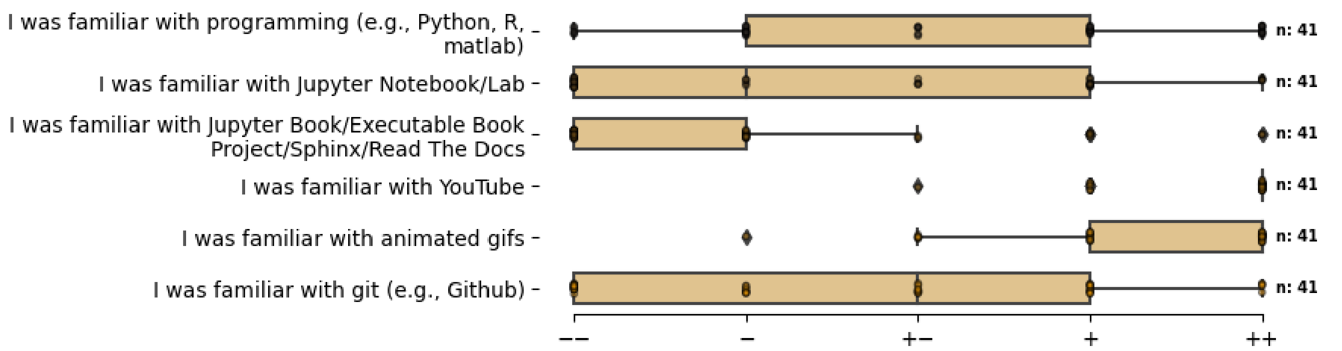

Figure S2.1. Assessment of prior knowledge/experience to the implemented digital tool sets one which the compendiums are built.

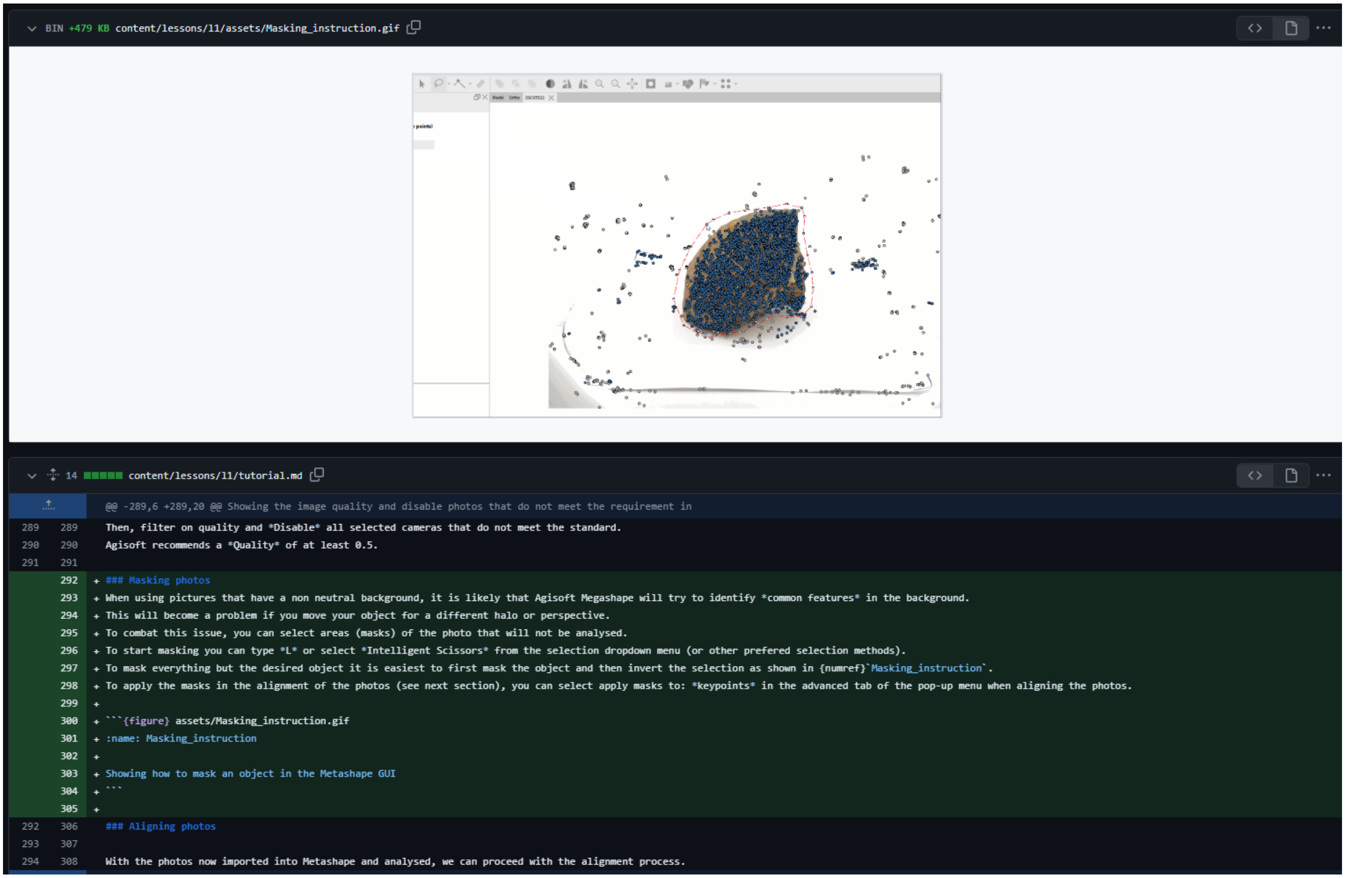

Figure S2.2. Student contributions ranged from single edits and suggestions, to multi-paragraph revisions and newly-recorded animations. Shown here is the student-contributed revision that documents the masking of photos in Agisoft Metashape and added it to the Geo-SfM tutorial (lesson 1). Note that the contribution is formatted in MyST Markdown and includes both text, an image code-block, and the self-recorded animation. Pull request link: https://github.com/UNISvalbard/Geo-SfM/pull/66.