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

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Abstract. Together with our students, we co-created two open-access geoscientific course modules using the Jupyter Book environment. We also assessed the Jupyter Book environment, integrated with GitHub to facilitate versioning, for its suitability for co-creation and open learning. The modules 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 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 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 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. Herein multi-disciplinary collaboration and student co-creation were key.

1 Introduction

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). In education, open pedagogy (OP) promotes a more democratic, accessible, and affordable learning environment by using open educational resources (OERs) instead of proprietary materials (Wiley and Hilton, 2018; Abernathy, 2023; Wiley and Hilton, 2018; Christiansen and McNally, 2022; Harrison et al., 2022; Matkin, 2009). OERs allow for retention, reuse, revisitation, remixing, and redistribution (5Rs), fostering collaboration and transparency that extend beyond the original creators (Audrey Azoulay, 2019; Caswell et al., 2008). They also increase the visibility and accessibility of educational content, encouraging broader participation (Jhangiani and Biswas-Diener, 2017; Barba et al., 2019). 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 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 collaboration (Project Jupyter, 2023; Granger and Perez, 2021). Jupyter helps break down problems and tell stories with code and data, 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 teaching. Recently, the Jupyter Book environment has emerged as an extension of the computational Notebook environment to include narrative and multimedia content (Executable Books Community, 2020). Jupyter Book allows for creating publication-ready books that integrate computational content (e.g., Jupyter Notebooks, scripts) and narrative content (e.g., text, images, videos) (Executable Books Community, 2020). These user-editable "unbooks" (Woodworth, 2011) work well with co-creation and version control tools like git, making them ideal for open publishing.

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 suitable for OER-P (Lambert, 2018; Biddle and Clinton-Lisell, 2023). First, we evaluate the pedagogical potential of co-creating Jupyter Books, their openness, and student's learning experiences. Second, we assess whether the Jupyter Book/GitHub co-creation framework can develop OERs with limited resources. Third, we examine student reception to the multimedia environment and conduct a brief study on optimal playback times versus 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 the Norwegian Arctic Archipelago of Svalbard. Both courses were taught and applied asynchronously

throughout the semester, with physical tutoring hours available over a one-week 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. It introduces structure-from-motion photogrammetry and provides detailed best practices. Subsequent years saw in-person teaching with revisions based on 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). 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 on project management, data structuring, and automation were also included.

After introducing the module layout, sessions, and key learning outcomes, students were shown the GitHub platform. They signed up and raised a simple "hello world" issue via the on-page menu bars at the course start. This helped them get familiar with GitHub's backend, including the issue tracker and online feedback tools. Students then worked through the course modules in pairs, using pair learning to enhance collaboration (Nagappan et al., 2003; Drey et al., 2022).

The GitHub platform, including its Classroom tools, has been shown to improve the educational experience for students and teachers (e.g., Zagalsky et al., 2015; Fiksel et al., 2019). 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 from students and other participants, forming the backbone of the co-creation and cooperative learning framework. This log

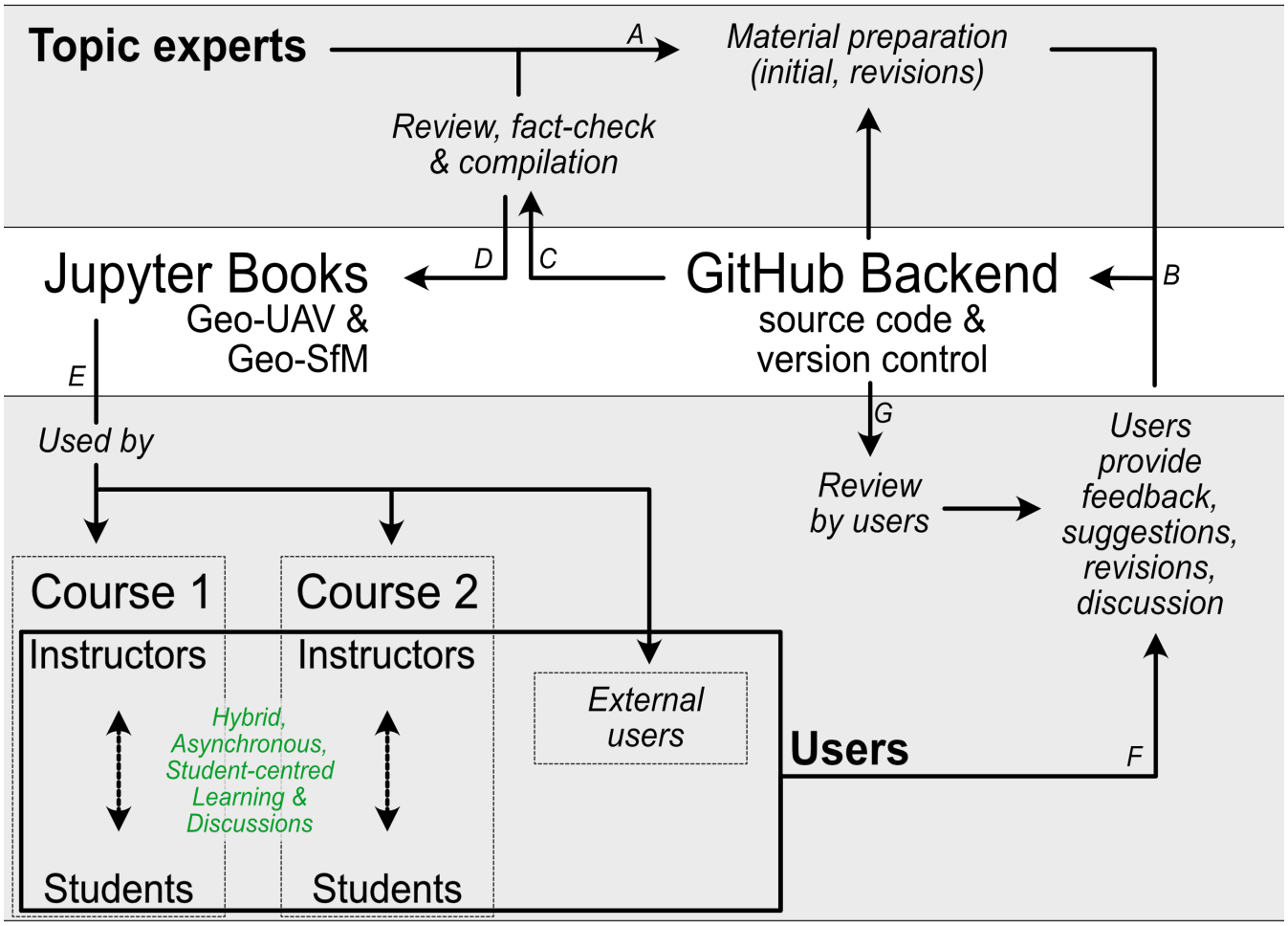

Figure 1. Instructional approaches of Geo-SfM and Geo-UAV integrating the GitHub backend for co-creation. Topic experts prepared the initial material (A), made it accessible through GitHub (B), and compiled the Geo-UAV and Geo-SfM Jupyter Books (C, D). These were subsequently used in Courses 1 and 2, 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.

of "improvable" sections (e.g., course content changes, more accessible phrasing, additional/revised visual and multimedia assets) was used to diversify teaching material and adapt content to students' styles and needs.

Starting in 2024, we introduced a three-hour tutorial on contributing through forks and pull-requests, based on feedback from the 2021 and 2022 courses. These tools allow sophisticated changes to the source code and expand how contributions can be made 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. 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 for questions and feedback from both students and instructors. The modules' setup, with gradual and asynchronous learning, 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 individual sessions was certified and documented in a course certificate, listing the accomplished learning objectives and their equivalents.

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, plain-language summaries, and static figures 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 Highfield, 2017). Their inclusion increases engagement and lowers participation barriers (Bakhshi et al., 2016). We used the LICEcap library (Frankel, 2023) for simple animated screen captures. It is lightweight, intuitive, and supports both Windows and OSX. LICEcap allows custom capture windows, intermittent recording, and on-screen text messages. We incorporated 31 looping animations, ranging from 3.8 to 78 seconds (Table S2.1).

Videos were recorded using Open Broadcaster Studio (OBS) (Kristandl, 2021; Bailey et al., 2017), a free, open-source software for screen recording, instructional videos, and online streams (Basilaia et al., 2020). OBS supports screen, window, and camera recording with configurable audio. We included 11 videos, ranging from 39 seconds to 6:28 minutes (Table S2.1).

During development, we appreciated the rich documentation from the Jupyter Book project (Executable Books Community, 2020). It offers detailed tutorials and a step-by-step guide on 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) and reStructuredText (.rst) files. The MyST syntax, an extension of Markdown, provides simplicity and power for creating rich content pages with text, figures, citations, executable code-cells, slideshows, and embedded files (e.g., 3-D interactive environments, videos) (Chen and Asta, 2022; Executable Books Community, 2020). Although not used in the Geo-SfM and Geo-UAV modules, pages can

integrate with cloud providers like JupyterHub (Project Jupyter, 2023) and Google Colab (Bisong, 2019) to facilitate executable content without local library installations.

2.3 Open Pedagogy study

The pedagogy study had two phases: the 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 (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 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 student co-creation options. First, students provided information on their educational backgrounds 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. 2) and qualitative (Table 1) questions about the integrated Jupyter Book and GitHub platforms, and the use of multimedia like GIFs and videos (Fig. 3). The latter specifically addressed different playback durations of animations and videos to assess student reception and determine optimal playback times versus self-assessed retention. Qualitative feedback was categorized as either *constructive criticism* or *positive feedback*.

The questionnaire was developed following the Norwegian National Ethics Committee's Guidelines for Research Ethics in the Social Sciences and Humanities (NESH, 2024). The study was internally reviewed by the University Pedagogy Programme at UNIS. Participation was voluntary, anonymous, and without rewards. The survey was available through the Jupyter Book modules, and students completed it online via Nettskjema, an online survey tool from the University of Oslo 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.

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). 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. Feedback was largely similar for both modules. Overall, students were excited about using the online modules,

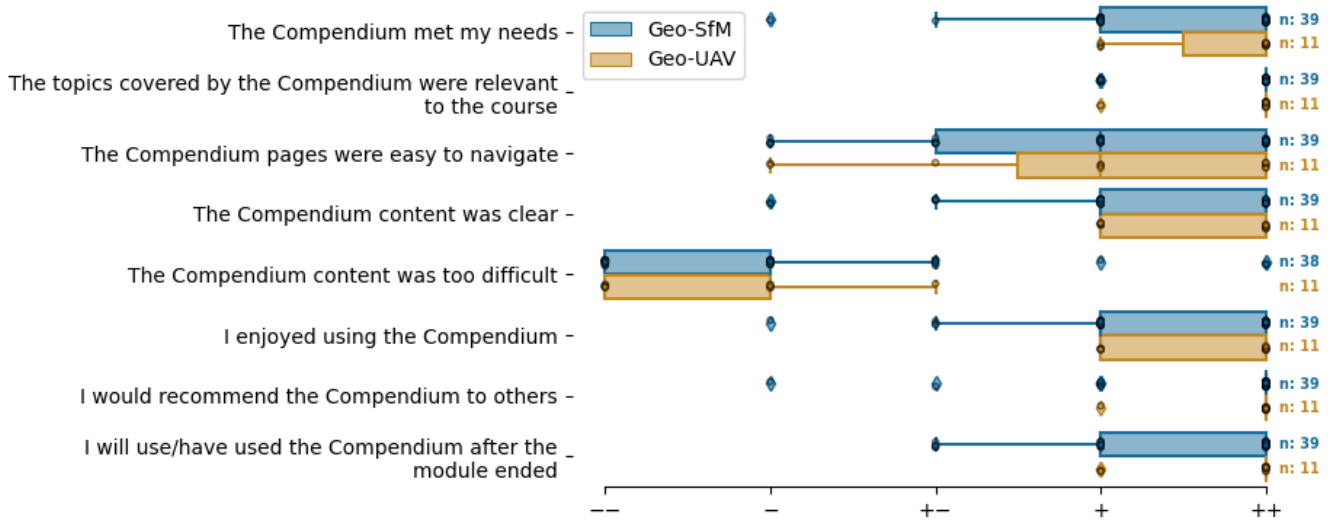

Figure 2. Quantitative student feedback on the Geo-SfM and Geo-UAV modules, here referred to as Compendiums. The bars, boxes and whiskers indicate the mean, one standard deviation and two standard deviations, respectively. Individual scores are separated for clarity.

felt the modules met their needs, and 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 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 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 aimed to create a diverse and accessible learning environment through multimedia integration and student-led content creation. 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. In response, students highlighted the benefits of

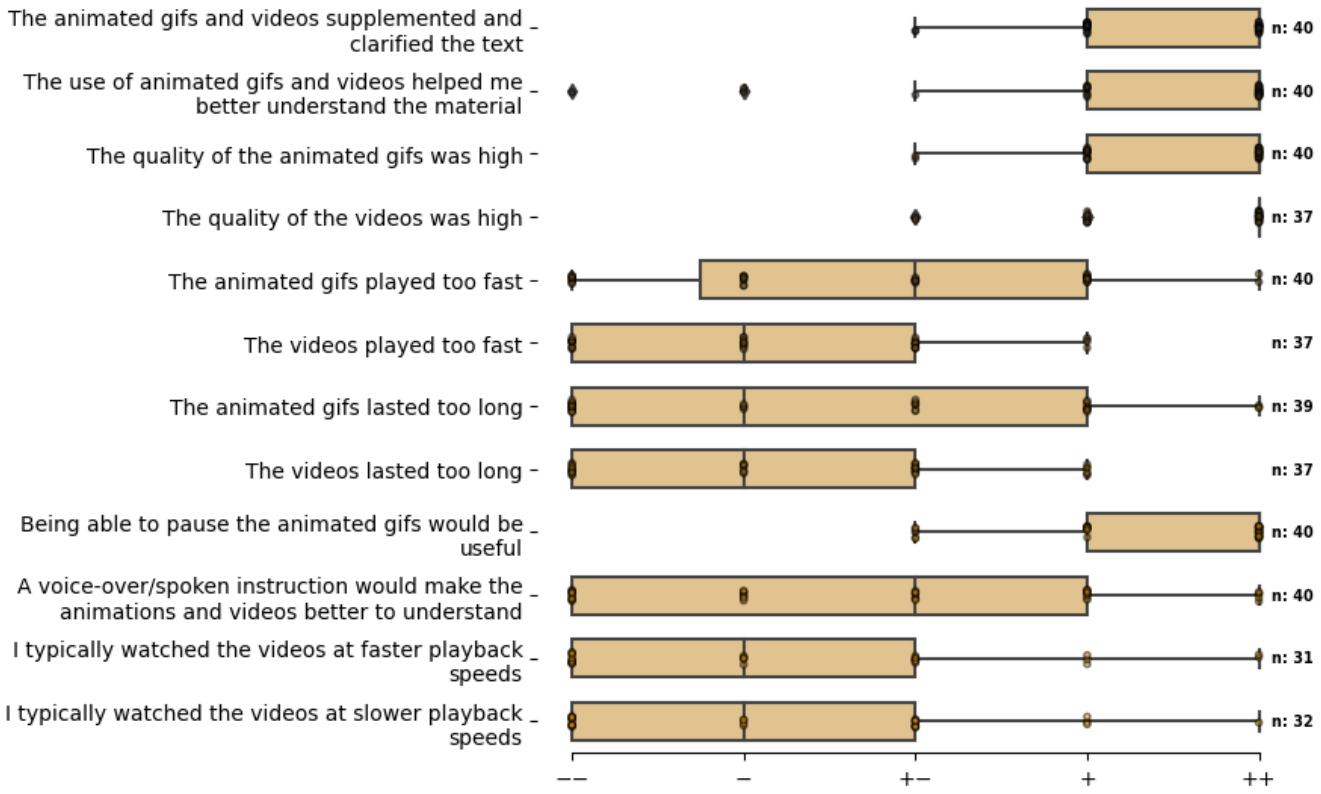

Figure 3. Student feedback on how well they experienced the inclusion of animations and video assets. The bars, boxes and whiskers indicate the mean, one standard deviation and two standard deviations, respectively. Individual scores are separated for clarity.

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 aligned with their quantitative feedback (Fig. 3). They agreed that animations and videos effectively supplemented the main text 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 needing to replay them multiple times to understand all steps (Table S2.2). Examples include not liking "to wait for the loop to end to see again the info [they] wanted to see" and 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-creation, eight students reflected on it through the open-ended survey questions. They noted that "being able to contribute to it [the modules]" and "also see other's contributions was helpful in filling in [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. However, this did not affect their sense of inclusiveness in content creation or their overall learning experience. Both cohorts felt it was inclusive to learn from previous student contributions and to improve resources for future use, becoming part of the community. The "use of GitHub/git to enable community contributions" was noted as a key factor that set the modules apart from previous learning experiences. 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 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.

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 drive engagement, interest, and exploration of concepts, which are crucial for learning and scientific thinking. Geo-UAV and Geo-SfM were designed with this in mind, tailored to support courses with students of varying experiences and abilities. 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 needing support.

Building comprehensive teaching materials and designing pedagogical feedback processes is challenging, yet can be eased through interdisciplinary collaboration between natural and physical scientists, social scientists, and students. 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 over the past four years, and certainly aided the design of the pedagogical framework itself.

Initially, we focused on assessing the technical usability of the modules and the Jupyter Book framework's learning potential, including multimedia and animations, 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 potential of the Jupyter Book/GitHub framework. The feedback we received provides a starting point and valuable 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, though they had some concerns about certain design choices. Many of these concerns have been systematically addressed during the four-year project, partly through student contributions and partly through social science insights.

In the following discussion, we integrated students' survey responses with our observations to evaluate the modules' openness, accessibility, and other pedagogical factors. This addresses the objectives from the introduction and helps us understand how students view the Jupyter Book framework and its potential for co-creative open learning.

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

Open-source curricula encourage participation, discussion, and co-ownership among students and the broader community, inviting everyone to collaborate on educational resources (Chen and Asta, 2022; Kim et al., 2021) Student feedback (Table 1) highlighted several advantages of the Jupyter Book/GitHub framework:

- **Learning effectiveness**: Step-by-step instructions and information in various formats and levels of interactivity were highly effective and provided a rich 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 with the tools and have opportunities to revise content, with 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, as creating cohesive content involves scientific problem-solving skills, which, as summarised by Barba et al. (2019), include Decomposition, Pattern Recognition, Abstraction, and Algorithm Design.

Given that the modules are openly available on the internet and provide accessibility by supplementing multimedia and user interactions, it is not surprising that the students rated the Geo-UAV and Geo-SfM modules favourably in terms of accessibility. A web search for "structure from motion photogrammetry tutorial" shows the Geo-SfM module among the top results in all top search engines, highlighting its practical accessibility. External contributions and feedback from four external participants also support this. In addition, the modules received positive ratings for clarity, ease of use, content diversity, and modern design. Indeed, some technologies and software were unfamiliar to students, but this was overcome through active facilitation, foundational work, and hands-on guidance by instructors. For example, introducing the GitHub backend and providing a brief tutorial on revising Jupyter Book files sparked interest in updating source materials, which was a recurring theme in student feedback (Table 1). 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. Through this, students not only became contributors, but also co-owners of the content. The collaborative experience enhanced teamwork, with student pairs working together on extensive

revisions, including multimedia (e.g., Fig. S2.2). Co-creation also heightened the sense of belonging, with one student noting that the ability "to make small changes to the actual site felt inclusive", and another student appreciating contributions from past years. Overall, co-creation led to pedagogic improvements, making the language and content clearer and better aligned with students' perspectives and understanding.

4.2 Design choices - lessons learned and future directions

Creating an initial environment for students to contribute to 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, requiring minimal time for student-led 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/GitHub, course content changes can be easily tracked and reintegrated with the source or used as a starting point for new educational content, contributing to community-driven OER development (e.g., Kim et al., 2021). This was particularly useful in developing Course 2, as we could build on the Geo-SfM module's history tracking and transfer previously removed side-notes on data acquisition to the Geo-UAV module. Version control documents changes, allowing instructors and students to visualize changes over time and reinstate previously removed content. It also helps mitigate loss of knowledge due to e.g. faculty turnover, loss of licenses, or sudden machine failure.

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, and they found extensive cross-linking between modules, especially in Course 2, confusing (Table 1). Thus, introductions to the Jupyter Book interface, 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 takeaways presented in this study, itemised in Appendix S1.

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 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 crucial for learner-centred and asynchronous learning (Georgiadou and Siakas, 2006).

The use of GIFs played an important role in accomplishing both objectives. GIFs provided visual, step-by-step instructions that simplified abstract concepts, supplementing the narrative text with easy-to-follow graphics. They are easy to create, have

low file sizes, and feature a low participation barrier for co-creation, as shown by student pull requests (Fig. S2.2). The format is excellent for short visual instructions, 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 need for balance. Further research is needed to optimize GIF content for teaching, similar to previous studies on videos (e.g., Guo et al., 2014).

With students co-creating and maintaining learning and multimedia resources, we saw a significant drop in preparatory workload. This allowed us to focus on more in-depth resources and specific content requested by students during their asynchronous learning. The modules thus shifted from a teacher-centric to a learner-centric model, centred around student-led discussions of findings and design choices. This freed up time for instructors to step in when needed. Students appreciated this approach, feeling a unique sense of inclusiveness and benefiting from a hands-on 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 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, 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. Such an effort certainly benefits from an interdisciplinary approach in which natural and physical scientists, social scientists, and students co-create 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.

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