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ABSTRACT

The emergence of digital tools, including tablets with a multitude of built-in sensors, allows gathering many geological observations digitally and in a geo-referenced context. This is particularly important in the polar environments where (1) limited time is available at each outcrop due to harsh weather conditions, and (2) outcrops are rarely re-visited due to the high economic and environmental cost of accessing the localities and the short field season. In an educational development project, we explored the use of digital field notebooks in student groups of 3–4 persons during five geological field campaigns in the Arctic archipelago of Svalbard. The field campaigns formed part of the Bachelor and Master/PhD courses at the University Centre in Svalbard in Longyearbyen at 78°N. The digital field notebooks comprise field-proofed tablets with relevant applications, notably FieldMove. Questionnaires and analyses of students' FieldMove projects provided data on student experience of using digital field notebooks, and insight into what students used the digital notebooks for, the notebooks' functionality and best practices. We found that electronic and geo-referenced note- and photo-taking was by far the dominant function of the digital field notebooks. In addition, some student groups collected significant amounts of structural data using the built-in sensors. Graduate students found the ability to conduct large-scale field mapping and directly display it within the digital field notebook particularly useful. Our study suggests that the digital field notebooks add value to field-based education in polar environments.

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Introduction

Geologists study an area's geological history by understanding the spatial and temporal evolution of a wide range of earth processes, through observing isolated outcrops. Learning in the field is therefore a fundamental aspect of geological education, resulting in both cognitive and metacognitive gains for students (Hannula, 2019; Mogk & Goodwin, 2012; Orion & Hofstein, 1994; Petcovic, Stokes, & Caulkins, 2014; Stokes & Boyle, 2009). Mogk and Goodwin (2012) provide a comprehensive synthesis of how field learning fosters undergraduate students' development of cognitive, affective, metacognitive and social aspects. Notably, learning outcomes associated with field learning are governed by a broad range of geologic (e.g., terrain characteristics, geological complexity) and non-geologic (e.g., weather, food, tiredness) factors (Stokes & Boyle, 2009). The affective responses generated by these factors undoubtedly impact the learning outcomes, as comprehensively documented in a typical undergraduate 9-day field mapping course in Spain (Stokes & Boyle, 2009). Optimizing field learning involves careful preparation to reduce the "novelty space," through for instance introducing the study area in seminars, practicing field methods in less challenging conditions and providing a clear outline of what the expected tasks and activities will be (Orion & Hofstein, 1994).

The geological field notebook is a vital instrument to document one's own observations from numerous localities (Coe, 2010; Stow, 2005). It is the original scientific record of observations (Stow, 2005), and it is thus imperative that it is managed in a logical, thorough and structured way. This includes recording observations (e.g., field sketches, descriptions), quantitative and qualitative data (e.g., sedimentary logs, structural measurements) and notes in a geographical context. New digital technologies have changed the way geoscientists work including how field campaigns are planned and conducted, and how data are gathered, analyzed, presented and shared (House, Clark, & Kopera, 2013; Lee, Suh, & Choi, 2018; Lundmark, Augedal, & Jørgensen, 2020; Novakova & Pavlis, 2017, 2019). Digital technologies for field use are, however, not usually designed for the harsh climatic conditions of the Arctic.

The University Centre in Svalbard (UNIS) offers undergraduate and graduate geology courses on the high Arctic Svalbard archipelago (74–81°N, 15–35°E), utilizing the superbly exposed vegetation-free outcrops ranging from Precambrian to Paleogene in age (Dallmann, 2015; Worsley, 2008). In such settings, efficient collection of reliable and

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Figure 1. The digital field notebook used at UNIS. Hardware consists of a field-proofed iPad 9.7″. An external battery pack that can be kept in an inside pocket is essential during winter-spring field work. The stylus-pen significantly improves usability in cold and windy conditions.

complete field data is arguably more important given the remoteness of outcrops, the short field seasons and the high economic and environmental costs of fieldwork. As such, outcrops are rarely re-visited by the students. The harsh climate also hampers student data collection during field excursions (Senger et al., 2018).

We developed a digital field notebook (DFN) comprised of numerous off-the-shelf hardware and software tools. The DFN assists the students to obtain geo-referenced and reliable field observations. They can then place these in the relevant space and time of Svalbard's geological evolution. The DFN is an integral part of a larger-scale digital toolbox, the Svalbox database (Senger, 2019; Senger et al., 2019). Svalbox provides an important bridge between observations in the field and the preexisting geological information from an area. The digital data collected by students are designed primarily to enhance the students' learning outcomes. We foresee that, in the near future, digital data collection may also be utilized in community-based student mapping projects, as has been applied in temperate latitudes (Whitmeyer, 2012; Whitmeyer, Pyle, Pavlis, Swanger, & Roberts, 2019).

Digital field acquisition systems were developed by the national geological surveys during the 1990s (Briner et al., 1999; Broome, Brodaric, Viljoen, & Baril, 1993). Pavlis, Langford, Hurtado, and Serpa (2010) reviewed some of the workflows and experiences using in particular the ArcPad and GIS-based systems for geological field mapping. Over the subsequent decades a number of field-based geology-focused tools were presented, including the GeoPad ruggedized PC system (Knoop & van der Pluijm, 2006), the Windows-based Fieldbook (Vacas Peña, Chamoso, & Urones, 2011), and Utah Geological Survey's rugged military-grade tablet computer (Brown & Sprinkel, 2008). Clegg et al. (2006) reviews the hardware and software available in the early 2000s, while Novakova and Pavlis (2019) provide a comprehensive review of the structural mapping capabilities of some of the presently available smartphones.

The rapid global adoption of smartphones (e.g., Lee, Chang, Lin, & Cheng, 2014 and references therein) has, in recent years, become commonplace also in the traditional geological field mapping domain (Novakova & Pavlis, 2019; Whitmeyer et al., 2019). Many smartphones include built-in sensors such as magnetometers, gyroscopes, accelerometers and GPS units that can be used to determine orientation of geological features. Other sensors, including proximity, temperature, barometer, microphone and optical image are also relevant for geoscientific field work (Lee et al., 2018). Numerous tools are available for both iOS and Android devices (e.g., Allmendinger, Siron, & Scott, 2017; Lee et al., 2018; Marcal, Viana, Andrade, & Rodrigues, 2014; Novakova & Pavlis, 2017; Weng, Sun, & Grigsby, 2012; Wolniewicz, 2014), though many suffer from lack of updates with newer versions of operating systems (Senger et al., 2019). Novakova and Pavlis (2019) conclude that the iOS tools perform better than Android devices, and that the most modern tools provide improved data collection. This is in line with previous studies on Android (Novakova & Pavlis, 2017) and iOS devices (Allmendinger et al., 2017). Cawood, Bond, Howell, Butler, and Totake (2017) compare the usability of the iPad-based digital compass-clinometer compared to virtual outcrop models and traditional field mapping, and suggest that the digital compass locally suffers from scattering and deviation, suggested to be due to sensor drift that can be rectified by sensor recalibration.

The majority of the published research focuses on the use of digital field tools for geological mapping or research, with limited research on the use of such emerging technologies in education (Lundmark et al., 2020). Their use in sub-optimal harsh polar conditions is undocumented thus far. In this contribution, we aim to systematically document how DFNs can be used in improving the learning experience while conducting field work in the high Arctic environment. Specifically, we aim to (1) present the DFN concept including hardware, software and best practices, (2) investigate undergraduate and post-graduate geology students' experience in using DFNs in a range of seasons through questionnaires, and (3) analyze the students' FieldMove projects to gain insight into what the students used the DFNs for.

Table 1. Overview of applications currently used in the digital field notebook, in order of importance.

Application	Purpose
FieldMove	Digital notebook, organizing notes, photos and observations in a geo-referenced environment. Measurement of strike and dip of planar geological features such as faults, fractures or bedding planes, measurements of plunge/trend of linear features and plotting such data in real time in a geo-referenced context.
Geoviewer	GIS-viewer primarily used for locating position on provided and offline regional geological map.
Svalbard Guide	GIS-viewer used for locating position on offline topographic map of Svalbard.
Documents	File manager to access relevant material such as reading list, maps, textbooks, tutorial movies or pre-field work assignments.
Camera	Standard camera tool for making higher-resolution photos than FieldMove, panorama images or videos.
Mail	Standard mail program to facilitate the data transfer onto the digital field notebook.
GeoTimeScale	Reference application for the geological time scale.

Finally, we discuss future investigations to learn more about how the DFNs can contribute to the field-based learning outcomes of the investigated courses.

Methods and data

What is a digital field notebook?

We consider the DFN as selected off-the-shelf hardware (Figure 1) and software (Table 1) products that collectively facilitate student learning in the field. For the hardware, we use a standard iPad with a rugged, field-proof, case (Survivor All-Terrain Rugged Case; Figure 1). The iPad has 128GB of storage capacity, a 9.7 inch Retina display, an 8MP in-built camera, a GPS/GLONASS unit, cellular capability, a 3-axis gyroscope, an accelerometer and a barometer. According to the manufacturer the operating ambient temperature ranges from 0 °C to 35 °C but we routinely use it in temperatures significantly below –5 °C. The cellular version is required even if operating in areas lacking mobile network coverage, since only these units have in-built GPS. Important accessories include a stylus pen for operating using gloves (Trust Stylus Pen) and a sufficiently large external power bank for use in sub-zero conditions (TP-Link TL-PB with a capacity of 10,400 mA). The total cost is approximately €600 per unit. We have also tested touchscreen-compatible gloves (Mujjo Touchscreen Gloves) but found that they wear quickly during geological fieldwork and are inferior to the stylus pens that can be easily held even in snow scooter mittens.

The key software components that are preloaded in the DFN for the students are listed in Table 1. In the courses outlined in this study, the DFNs are used by groups of 3–4 students. In addition, each student uses an individual traditional all-weather geological field notebook (Figure 1) to practice the important field sketching and note taking skills and to act as a back-up to the DFNs in case of hardware failure. As such, the DFN is a complementary tool and the group members are encouraged to share it with each other.

Implementation of the digital field notebooks in UNIS courses: Course overview and seasonal variability

In 2017, we fully implemented the use of DFNs in three consecutive bachelor (BSc) groups in the spring field season during a snowmobile-based excursion and in two graduate (combined master [MSc] and doctorate [PhD]) student groups during late summer in a combined excursion-group data collection setting (Table 2; Figure 2). A total of 102 students participated in these courses, and 69 of these responded to the post-field trip DFN questionnaire. The numerous courses encountered a range of weather conditions, from adverse to relatively pleasant (Figure 3). Furthermore, we have gained significant experience through using the DFNs during research projects at MSc, PhD, and post-graduate researcher level. The courses at UNIS comprise the full-semester BSc package (AG209 and AG222; Table 2) which makes optimal use of the snow-scooter based field season, and individual ca. 5 weeks long graduate level courses held mostly in summer (AG×36; Table 2; AG×36 includes both the MSc AG336 and PhD AG836 courses taught simultaneously). The field excursions typically last 4–8 days at BSc-level, but can be somewhat longer at graduate-level (Table 2).

Field excursions and field work in Svalbard, located at 78°N depend on seasonal conditions (Figure 2). Snow-cover and good light conditions in March–April facilitate snowmobile-based excursions. Significant (average 100 km/day; Figure 2B) snow-scooter driving is required to visit the key localities and require careful planning. Snow cover, for instance, makes some key sites unsuitable for winter/spring field work. The more traditional field season during the short summer from July to September relies mostly on coastal and near-coastal outcrops that can be accessed using boats or by walking. Remote inland localities easily accessible using snow-scooters in the springtime become virtually inaccessible in summer-time unless helicopter drop-offs are possible. The long polar night effectively restricts geological work in the winter months to indoor analyses of drill cores.

The temperature and wind speed as measured in Adventdalen near Longyearbyen during the five separate field campaigns is shown in Figure 3. The average temperature for the three spring-based field campaigns was –12.7 °C, while average temperature in the summer campaigns was 2.9 °C. The wind speed, an important contributor to reducing temperatures through the wind chill factor, was significant in both spring and summer. Clearly, local variations in temperature, wind speed and precipitation are expected over such large areas, but we almost always operate below the stated

Table 2. Overview of field campaigns where digital field notebooks were utilized, along with a summary of quantitative grading of selected practical aspects of using the digital field notebooks.

UNIS course code and name	Level	Number of students	Timing of field period	Number of FieldMove projects	Respondents to FieldMove questionnaire	Average score*					Gloves?	Stylus pens?	Battery packs?
						Overall usability	*Geological measurements*	*Battery life*	*Frozen fingers*	*Screen glare*			
Spring courses													
AG-209 Tectonic and Sedimentary History of Svalbard (2017)	Bachelor	25	16 March and 22–27 March 2017	5	25	2.8	2.1	4.0	4.9	1.3	N	N	N
AG-222 Integrated Geological Methods: From outcrop to geomodel (2018)	Bachelor	20	5 April and 8–11 April 2018	5	12	2.0	2.3	4.1	4.8	2.0	Y	N	N
AG-222 Integrated Geological Methods: From outcrop to geomodel (2019)	Bachelor	20	25 March and 1–4 April 2019	5	12	2.3	2.8	2.9	3.1	1.5	N	Y	Y
Summer courses													
AG-×36 Rift Basin Geology: From outcrop to model (2017)	Master/PhD	18	10–18 September 2017	6	16	1.9	2.9	1.6	3.1	1.7	Y	N	Y
NfiP Petroleum Field School, Billefjorden (2018)	Master/PhD	19	11–15 September 2018	5	4	2.3	2.0	1.8	3.0	2.0	N	Y	Y

*Scores are given for each practical aspect, with 1 signifying no problem at all, while 6 suggesting it renders the tool unusable.

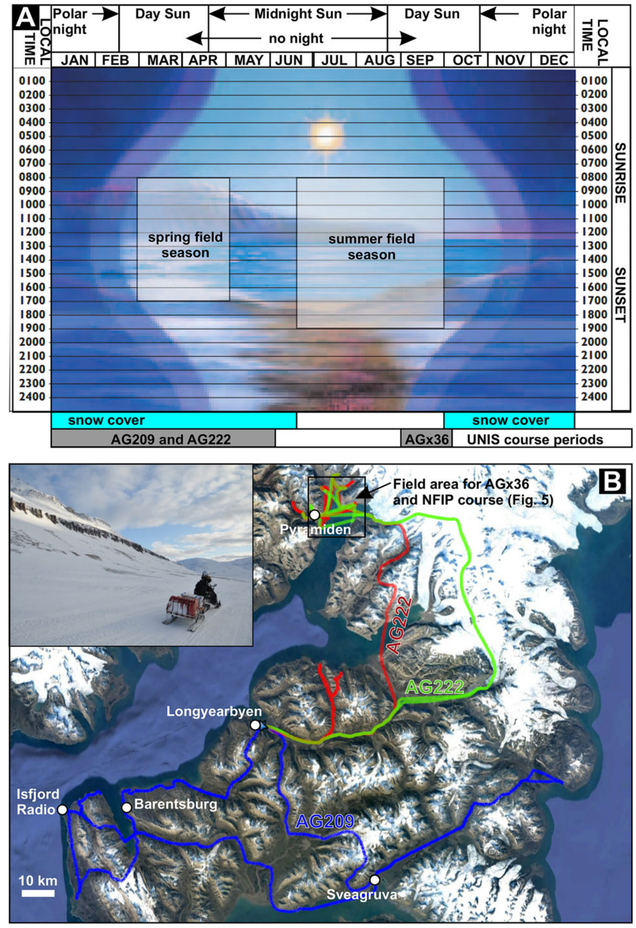

Figure 2. Synthesis of the Arctic field work campaigns. (A) Modified sun diagram for Longyearbyen illustrating the strong seasonal dependence for conducting field education in Svalbard. Sun diagram provided by the Longyearbyen Community Council. (B) Location of the various field campaigns analyzed, on a satellite image base map from Google Earth. The inset image illustrates the snow-scooter based transportation.

operational limit of the DFN. The use of external battery packs, touchpad stylus pens and keeping the DFN within the warmth of the snow-scooter suit when not in use makes it feasible to utilize the DFN in such conditions.

Students' experiences of the digital field notebooks

Prior to field campaigns, students completed online questionnaires aimed at identifying the students' specific geo-scientific background and experience using digital field tools (Figure 4). Information from the questionnaires guided group assignment where existing expertise was distributed. During field campaigns, the students were assigned to groups of 3–4 students, with the aim of combining complementary expertise and experience.

Following the field campaigns, we utilized an anonymous online questionnaire to gather student experiences on their usage of the DFN, forming the foundation of this research project. The questionnaires were distributed online immediately following the field component, and the response rate was high ($n = 69$, out of a maximum possible of 102) in all but one course (Table 2). The online questionnaire, utilizing the Google Forms platform and provided in Supporting Information, was developed based on our previous

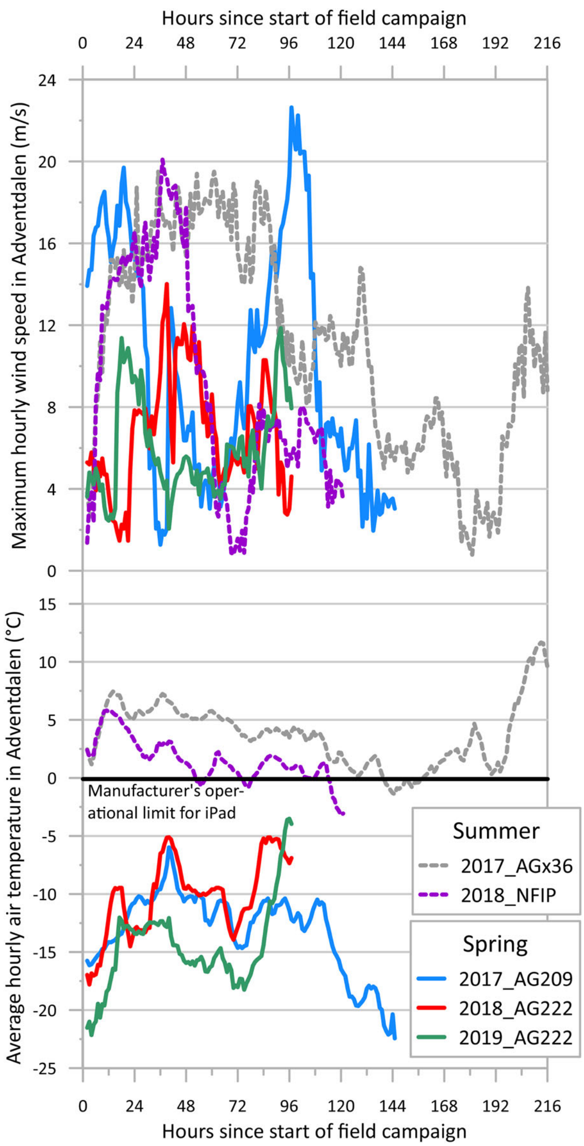

Figure 3. Average temperature and maximum windspeed during the respective field periods, as measured hourly in Adventdalen (Data source: UNIS, www.unis.no/resources/weather-stations/). Note that there are strong regional air temperature gradients, in particular from the relatively mild western coast to the east (Przybylak et al., 2014).

experiences of using the DFN for our own research prior to its implementation in field learning. No direct incentive was offered to complete the anonymous questionnaire, but the students were told they are voluntarily contributing to ongoing research and curriculum evaluation. Responding to the questionnaire had no effect on the students' course grade, which was assigned based on exams, presentations and research projects in the different courses. No personal data were collected in the anonymous questionnaire, and the research thus does not require approval by the Norwegian Center for Research Data. In addition, we systematically analyzed the FieldMove student group projects to gain insight into what the students primarily use the tools for. This involved plotting the data acquired by the students in map view in Google Earth (using the .kml file exported from the FieldMove project), amongst others to control that all observations, measurements and photographs were assigned to the correct localities. The FieldMove projects were inspected and photos, notes and geological measurements conducted by each group were categorized. Particular attention was given to how the different observations are linked. For instance, students were encouraged to document the different field sites with overview photos, outcrop-scale photos and detail photos of key observations. The group FieldMove projects were not linked to the individual anonymous survey results. The first author was the course co-ordinator and teacher in four of the five campaigns and observed the students in the field as well as informally discussing their experiences with the DFN. The insight into the students' experiences and use of the DFNs gathered in this manner has been useful in mapping out the students' usage of the DFNs.

Results

Mapping students' prior experiences

The precourse questionnaire illustrates that all students own a smartphone, though 25% have owned it less than 1 y (Figure 4). Approximately two thirds rely on the iOS operating system, with Android largely making up the remainder. Only a quarter of the students own a tablet. The majority of students had no previous knowledge of using digital tools in the field, and 80% of students had no prior experience with the FieldMove application. In order to maximize the students' gain from the DFNs, a 2–3 h hands-on training session was implemented into the courses to introduce the students to the tools and their functionality. In addition, a single field day during the AG222 course focused on using DFNs in the outdoor environment.

What are digital field notebooks used for and when?

We mapped out the students' usage of the DFNs by observing them in the field, gathered responses through the questionnaire and studied the delivered FieldMove projects (Supporting Information Figure SM1). The video in the Supporting Information provides further insights into the field usage of the DFNs, and the at times challenging learning conditions. The main advantage of the system is that all observations, photos, notes and structural measurements were georeferenced and directly displayed on the base map within FieldMove. The complementary Documents application allows easy offline access to reading material, lecture notes, reference textbooks and videos downloaded onto the device prior to fieldwork. A typical workflow for the students conducted at each locality is listed in Table 3, and the significance of the DFN at each step follows. The workflow, with the field part illustrated in Figure 5, is based on the snowmobile-based AG222 field campaign, but is in general applicable to all the investigated courses. The main difference between the different campaigns is the time available at each outcrop and the level of expert support. In undergraduate courses, outcrops are visited only once and for a relatively short time (approximately 30–90 min) with the course instructors and teaching assistants able to provide input. Graduate-level courses, on the other hand, allow the students themselves

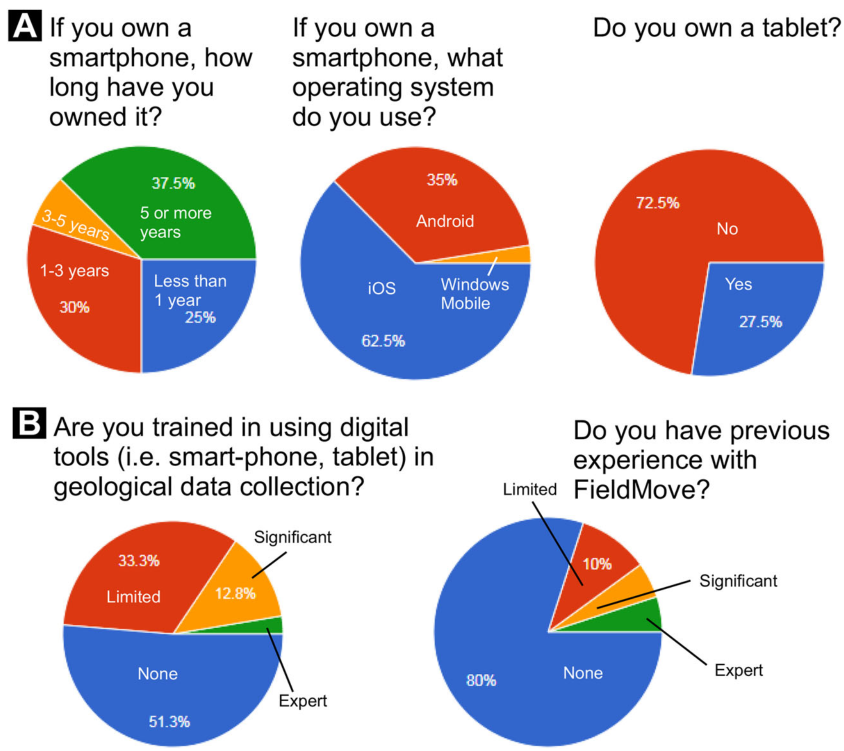

Figure 4. Summary of the precourse questionnaire mapping exposure to the digital field toolbox. (A) Exposure to smartphones and tablets prior to the course. Note that all respondents indicated they own a smartphone. (B) Students' previous experience in utilizing digital tools, and FieldMove in particular.

to manage their time and may, involve detailed analyses of an outcrop over several days, though typically without continuous expert supervision.

The DFN was implemented as a group tool, with group size varying from 3 to 4 students, making it difficult to quantify the individual usage per student. Field observations by the first author, however, suggest that the student groups typically had several students responsible for the DFN, utilizing them interchangeably at the locations. Based on the questionnaires we found that approximately one third of the respondents used the tool at every locality, of which there can be several during a field day. Another third used it daily, with the remainder using it at irregular intervals often associated with sharing the tool between the different group members.

Students reported that they mostly use the DFN at the outcrops during the field excursions for geo-referenced note taking, photographing and measuring strike/dip of geological strata, summarized in Supporting Information Figure SM1. In addition, the DFNs were also used during the evenings at base camp and upon returning to Longyearbyen, for instance to digitize the individual traditional field notebooks by taking photographs of all pages in the FieldMove app and thereby share observations between group members. The ability to collect everyone's field notes in the DFN was considered positive throughout the investigated courses (Table 4). The students were not doing field sketches directly on the iPad, even though there are numerous drawing apps available. This is primarily because the tablets are a group tool, and the teachers wanted to provide fair feedback for the entire class using the same medium (i.e., field sketching in field notebook).

The DFNs are ideally used prior to the field campaign, during the field campaign and following the field campaign (Table 3). The preparation of topographical and geological base maps, for instance, already allows the students to familiarize themselves with the study area, thereby also reducing the novelty concept (Orion & Hofstein, 1994). For the AG222 2019 field campaign, each student group was assigned the coordinates for two outcrops that they should prepare a 5 min presentation upon arrival to the outcrop. A synthesis of the main learnings from each outcrop was subsequently repeated in the classroom. Similarly, the field observations recorded on the DFN were directly utilized for the concrete summary report or task, which differed from course to course. For the AG222 2019 campaign, for instance, this involved putting together a license claim application to "apply" for exploring for petroleum within the investigated field area.

The perceived strengths and weaknesses of the DFN for the different courses are summarized in Table 4, and detailed statements from the students on the different courses are provided in Supporting Information Table SM1. On the positive aspects, the geo-referenced data collection, organizing a wide range of relevant observations, measuring strike/dip and instant visualization of field data all scored well. On the other hand, cold fingers, a bulky unit, at times unreliable measurements and lack of easy post-field work analyses software were considered as challenges to DFN usage.

General and site-specific usability of the digital field notebooks in Arctic conditions

The students' responses mapping their experience with hands-on usage of the DFNs are summarized in Figure 6, with

Table 3. Overview of a typical sequence of tasks the students are to conduct at a specific field locality.

Task	Task description	Comment	Role of digital field notebook
1	Pre-field work preparation	Each group prepares background material for 1 stop per day, including overview slides placing the stop in the context of a geological map, regional cross section and stratigraphic column	Relevant literature, figures, base maps and virtual outcrop models to be stored on DFN
2	Travel to field site	Mostly by snowmobile or boat, can be days or even weeks after preparation	Easy overview of how localities relate to each other spatially, especially important when snowmobile or boat is used for transport between localities
3	Locate yourself on the topographic map	Using screenshot of the GPS-enabled topographic map	Use "Svalbardguiden" app
4	Locate yourself on the geological map	Using screenshot of the GPS-enabled geologic map	Use "GeoViewer" app
5	Acquire overview photographs or sketches	To document the outcrop quality, coverage and overall setting with respect to key features of the studied basin	Combine panoramic photos (high-resolution) with photos from FieldMove (lower resolution, but shows direction photo was taken in)
6	Observe the outcrop	Document key features, including first-order rock description (texture, color, bedding, sedimentary structures, structural features, etc.)	Use digital notebook and photos
7	Conduct quantitative measurements	Using iPad or traditional compass, measure relevant features (e.g., bedding planes, fractures, faults, intrusion contacts) and display them directly in the field	Use digital compass clinometer built-in in DFN to acquire and directly display data
8	Produce sketch-log or sedimentary log	Describe the observed stratigraphy	Use traditional notebook or Stratlog app
9	Take relevant samples	Acquire hand samples where relevant, documenting which unit they belong to	Document using FieldMove app
10	Digitize the outcrop	Depending on coverage, quality and time, consider digitizing the outcrop using photogrammetry	Take geo-referenced photos using iPad or at least document on iPad which section was digitized
11	Synthesize and summarize observations	As a class, share the observations directly in the field and discuss their significance in interpreting the geological evolution of the area	Note-taking, particularly important for the group responsible to synthesize the outcrop
12	Student presentations	Upon return to field camp or university, synthesize the main message of the group's assigned localities	Direct use of DFN during presentations, or use of material exported from presentation
13	Data processing, sharing and archiving	Conduct photogrammetric processing, digitize traditional field notebooks, re-draw sedimentary logs, share data amongst group and class, export FieldMove projects etc.	Important data source with all collected field data, sharing and digitizing of traditional field notebooks
14	Integrate new and existing data	Consider whether additional data, such as virtual outcrop models from a different season, can be meaningfully integrated with own observations	See Task 1 regarding overview of preexisting relevant material
15	Documenting and reporting	Produce field reports utilizing the observations from the field campaign(s)	DFN facilitates reporting and FieldMove project is part of the required documentation

The time spent at each locality can range from approximately 30–45 min during whole-class excursions, to several days on the graduate-level courses where group work is required.

average values reported in Table 2. The most important parameter is the overall usability of the DFN, and here the vast majority of respondents provides a grade 3 or better on a scale from 1(best) to 6 (worst). Second, the usability of the geological measurements, including measuring and plotting orientations of observed features such as fractures or bedding planes, is generally considered good with average scores between 2.0 and 2.9. Some students, however, were concerned about the inaccuracies of the digital compass measurements. These were often related to external interference related to the presence of geological hammers, rifles, transmitting avalanche beacons or mobile phones. All measurements, in particular the strike, were quality-controlled by plotting the data on the digital map, and by conducting multiple measurements of the same surface. Students were also asked to compare the measurements from the digital compass with analog methods, which was particularly emphasized during the training session.

Battery life and frozen fingers represent significant challenges when using the DFN, particularly in the spring field season courses AG209 and AG222. Cold fingers also caused some issues in the AG×36 course held in summer, though battery life appears to be very good. A greater proportion of high scores is evident from 2018, when external battery packs were introduced. Screen glare does not appear to be an issue at all, though a few people in 2018_AG222 and 2017_AG×36 voiced complaints related to the bright sunlight encountered. Overall, the respondents suggest that while there are certain issues, such as battery capacity and cold fingers, that require careful planning and remediation, there are no obvious impediments to utilizing the DFNs in the Arctic environment.

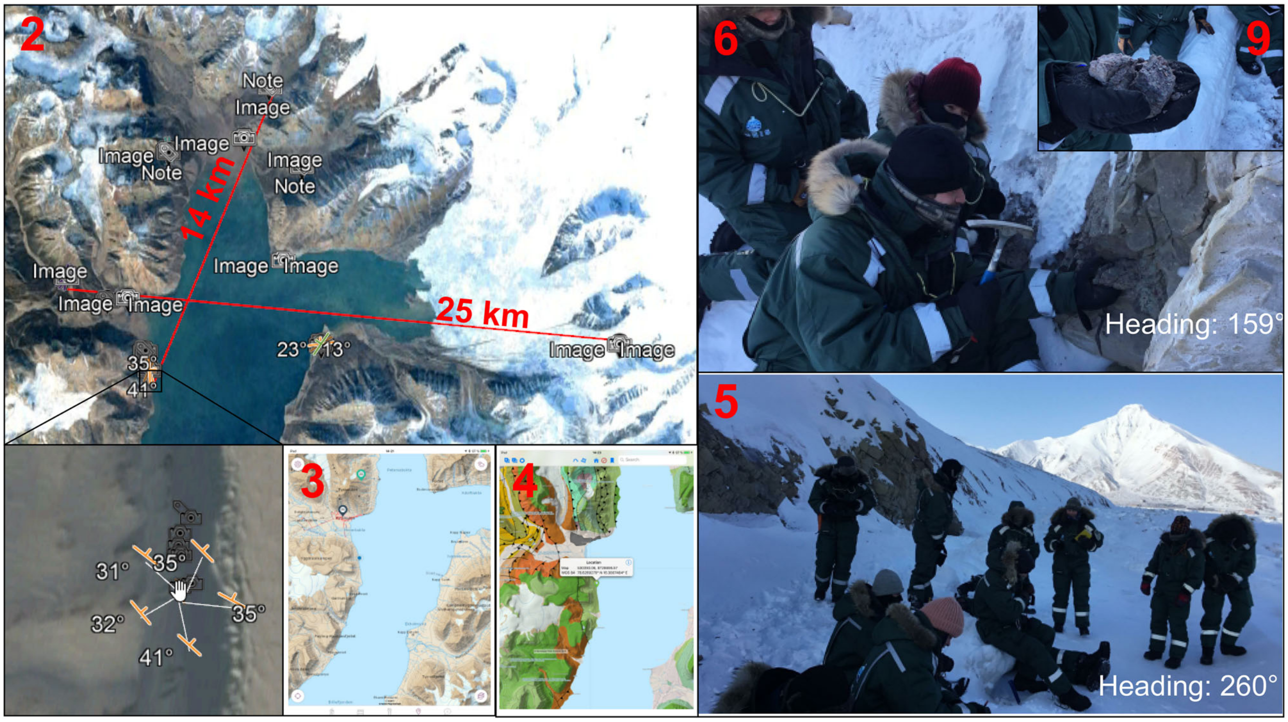

Figure 5. Synthesis of the usage of the DFN at a single locality during the AG222 course in April 2019, where an outcrop south of Pyramiden was visited. The entire field area is approximately 25 × 15 km large, and the visited localities are clearly marked in the students' FieldMove project visualized in Google Earth. The red numbers correspond to the tasks listed in Table 3.

Table 4. Synthesis of student's perceptions on the best and worst aspects of the DFN.

What did you like most about the digital field notebook?	What did you like least about the digital field notebook?
Connect pictures and locations	Take gloves off, cold fingers
Easier to take measurements than on compass	Did not trust the measurements
Take pictures while writing notes	Does not last too long in the field
GPS, Compass	It was a bit big, so not really handy, not pocket-size
Easy to use, fast to take notes	Lack of GPS on some units
Keeping «stuff» organized and geo-referenced	Taking strike/dip was unnecessarily difficult
Instant visualization of field data on stereonet	Application for stratigraphic logging
Data easy to export	No easy software for data analysis following fieldwork
Great for regional field mapping	
Fast measurements	

For details, refer to Supporting Information Table SM1.

From our experience, battery capacity is minimal (<15 min) in winter conditions (i.e., temperature $<-5\,°$C; Figure 3) if no external battery pack is connected. With a battery pack, carried within an inner pocket of the snowmobile suit, a full day (8 h) is achievable. In summertime, battery capacity is typically sufficient for several hours of operation, but is highly sensitive to temperature and usage, with GPS and extensive photographing for virtual outcrop modeling being particularly significant battery-draining activities.

Discussion

Impact of seasons on usability

Fieldwork in Svalbard is strongly controlled by the seasons (Figures 2 and 3), which is unsurprising given the influence of weather on all field activities in the high Arctic. In our study, the seasonal variation was mostly manifested by the battery life, where the two summer courses both score highly (55–75% of respondents indicated battery life being no issue) while all spring courses considered that battery life was a major impediment. For the DFN to function properly, an external power bank is required. Cold fingers were also primarily an issue in spring courses, but it is notable that the 2019 AG222 course, where stylus pens were provided to be used with mittens on, considered this much less of a problem than the same course in 2018 when only touch-screen gloves were provided. We do not consider the high percentage (50%) of the NfiP course considering frozen fingers a major problem given the low response rate ($n = 4$) for this course. There are limited seasonal differences with respect to screen glare and geological measurements. Finally, all courses score well on overall usability, with "2" being the dominant mark in all but one course. In summary, while the cold and windy spring season certainly requires some Arctic adaptations, the DFN is a year-round tool.

Undergraduate versus graduate courses

There was limited variation between the undergraduate (AG209 and AG222) and post-graduate (AG×36 and NfiP)

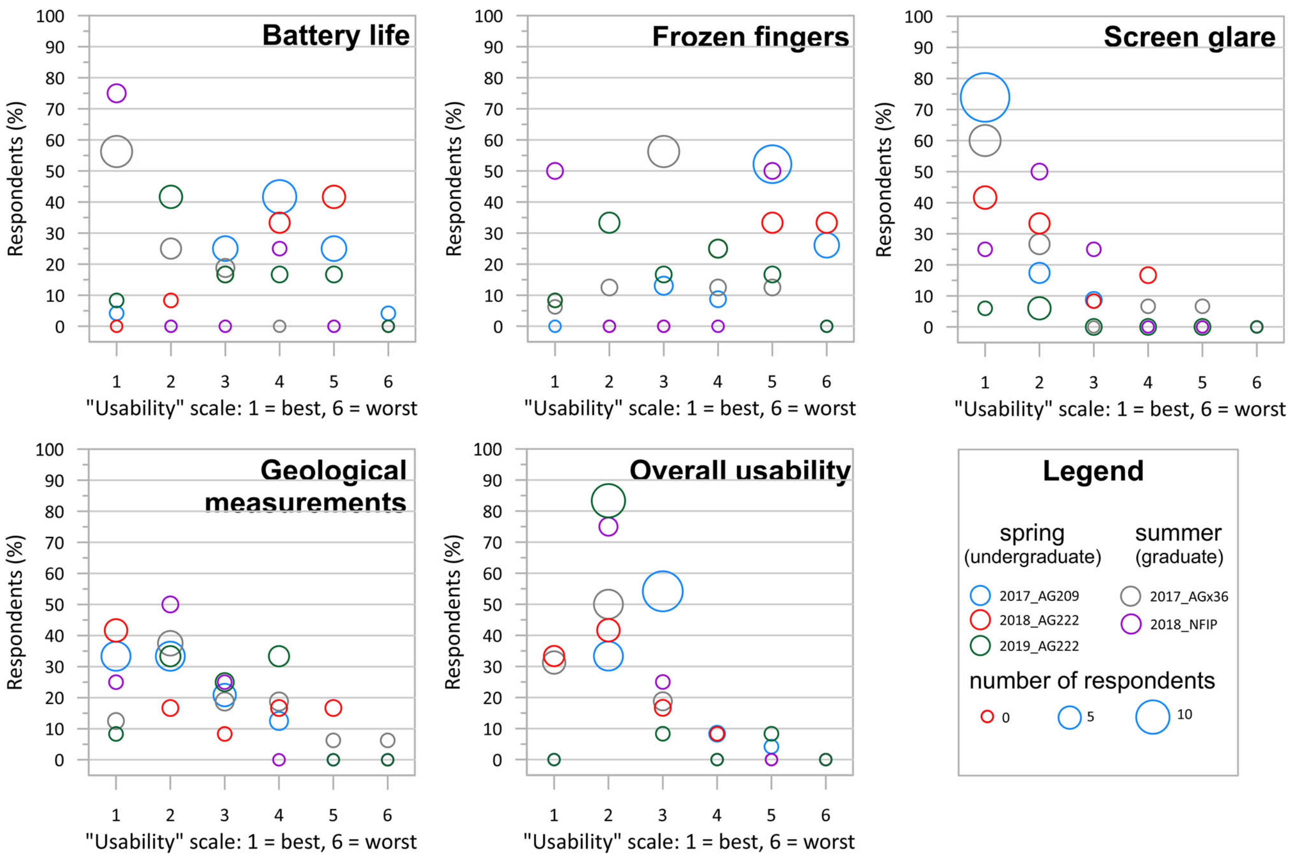

Figure 6. Responses to quantitative analyses of the practical aspects of using the digital field notebooks to identify any major impediments in their usage. The bubble plots illustrate the percentage of respondents spread across the "usability" scale, where 1 signifies no problem at all, while 6 signifies that this particular aspect renders the tool unusable. The size of the bubbles reflects the actual number of respondents, accounting for the span in both teaching class size and number of respondents. Average scores are reported in Table 3. For details on the different campaigns, refer to Table 2.

courses. A small number of post-graduate students in AG×36 found the geological measurements unsatisfactory to useless. This may be related to more critical thinking at the advanced level, with the students carefully quality controlling the geological measurements using a traditional geological compass. In contrast, most undergraduate students scored the ability to quickly gather the structural information so easily, very highly. Supporting Information Figure SM1 lists some of the student experiences from the different courses. The organizational aspect of FieldMove was positive in all courses, though it is notable that many of the graduate students appreciated the ability to plot measured data in stereonets and in map-form. Many graduate students also went beyond the field-based application of DFN, and some complained about the usability of the collected data following the field campaigns. Part of this was related to the different work tasks assigned, where graduate students to a much greater extent utilized the collected data in their own research projects.

Examining the delivered FieldMove projects, we find that undergraduate students are very good at recording teacher-provided information, particularly syntheses provided at the end of each geological stop. Students in MSc- and PhD-level courses, on the other hand, spend significantly more time independently of the teachers at outcrops, and recorded their own observations and measurements to a greater extent than the undergraduate students. Part of this difference is also related to how the different courses were organized, with many field excursions at the undergraduate level and a more individual or group-based field work component at the graduate level.

Adaptations and developments of the digital field notebook at UNIS

It is important to consider the DFN in conjunction with other tools (e.g., Svalbox; Senger, 2019) and traditional geological field techniques. As such, a DFN should not replace the ability of students to take structural measurements using a handheld compass, the ability to sketch in their traditional field notebooks or the ability to make their own observations at an outcrop. Instead, the DFN should facilitate reaching these tasks, for instance by allowing students to take key reference look-up textbooks and video tutorials with them to the field and structuring their observations within the FieldMove project. The traditional skills, including taking a structural measurement with a handheld compass, are amongst others still critical to quality-control the measurements from the DFN. Our experience suggests that such structural measurements are also more effectively and accurately conducted using a smaller smartphone rather than an iPad, given the necessity to place the device over the plane to be measured. Recent work at the University of Oslo, utilizing FieldMove by third-year BSc students during a field campaign in mainland Norway (Lundmark et al., 2020), supports much of our findings on the aspects of student usage, and additionally provides an added element of student perceptions' on when such digital tools should be implemented. The fact that most students prefer the digital tools to be introduced as early as possible in the university education (Lundmark et al., 2020), and that UNIS is Norway's "field university," suggests that the usage of tools like the DFN will expand in the short term.

We also consider the students' feedback to further develop the DFN. Some practical polar-specific issues raised regarding the unit size, battery capacity, GPS, and iPad cover issues or frozen fingers have been addressed through the purchase of additional equipment, including power banks, stylus pens, and iPad minis. Lack of dedicated software for sedimentological logging is rectified by including Strat Mobile (Allmendinger, 2018), a dedicated smartphone application. Furthermore, empty stratigraphic log templates will be added to future DFNs. Export and post-analyses workflows are also being standardized. The various aspects impacting the accuracy of the geological measurements, including interference from geological hammers, rifles and other metallic objects, is in itself a research subject that will be incorporated as future research projects in AG222. Finally, we consider the need to take virtual outcrop models to the field in the future, and preferably be able to directly include new observations. Kehl et al. (2017) outline some possibilities of offline mapping of photographs onto textured surfaces directly on mobile devices. This software is, however, not available on iOS. As an alternative, 3D pdf viewers (e.g., 3DPdfReader, Embed3D) are available but do not incorporate geo-referencing yet.

Implications on learning processes and learning outcomes

Geoscientists and geoscience educators alike consider field courses an integral part of geoscientific education (Dykas & Valentino, 2016; Mogk & Goodwin, 2012; Petcovic et al., 2014). Through linking observations at different scales and through geological time, there seems to be a strong potential for the digital technologies to facilitate student's learning of spatial skills. Shipley, Tikoff, Ormand, and Manduca (2013) consider field teaching of structural geology from a cognitive perspective, and recommend that students explicitly consider how certain geological features may be connected across different spatial scales. In this framework, the observations collected across a field area (e.g., a geological basin) and documented in a DFN provide an important tool, particularly if coupled with post-field work exercises on integrating the different observations and discussing their relationships.

Our study explored the use of DFNs with students at UNIS over 3 years and has documented important use as well as some challenges. A question for further exploration and study is in what ways the use of these new tools and technologies are changing the learning processes and the learning outcomes in geoscience at UNIS. These are relatively similar in many courses at UNIS given the field-based component, with for instance "Develop a basic understanding of geological field mapping techniques" (AG222) and "Be able to measure and analyze tectonic and sedimentary structures in the field, and to construct detailed logs through successions of sedimentary rocks" (AG336). Our study indicates that the DFNs facilitate the field-based data collection, especially with respect to structural data.

The DFN is no doubt a powerful learning platform. We need to further investigate to what extent the students use the variety of data stored in the DFN (Supporting Information Figure SM1) and in what ways such use helps them integrate local observations with the larger-scale structures and processes. We envision a follow-up study where students more thoroughly reflect on their learning processes, both orally and in writing, and we analyze these reflections to learn more about the students´ experiences. We are currently hiring a dedicated researcher who will observe the students in the field and take field notes of the observed learning processes. We also foresee dedicated efforts to quantify the efficiency of using a DFN compared to traditional field techniques in the High Arctic environment, for instance through collecting large amounts of quantitative structural data from the same near-town outcrop with both techniques. We plan to explore how the use of digital geological techniques, particularly DFNs and virtual outcrops (Senger et al., 2019), affects the student's spatial thinking skills, with dedicated pre- and post-field campaign questionnaires. Some of these studies will be conducted as part of the annual undergraduate course AG222, using individual and not group-based DFNs.

Conclusions

We implemented digital field notebooks (DFNs) in undergraduate and graduate university level courses in Arctic Geology in Svalbard in five geology field classes taught at UNIS, two in the summer and three in the winter/spring season. Field excursions typically last 4–8 days and are undertaken using snow-scooters in spring, and small boats and on foot in summer. The weather conditions were harsh in particular during the spring field campaigns, with an average temperature of –12.7 °C and significant wind speeds. This is well beyond the hardware manufacturer's stated operational limit of 0 °C, and external battery packs are critical to keep the DFNs operational under these conditions. Summer conditions are friendlier, but the low average temperature (2.9 °C) nonetheless requires efficient use of field time.

We have collected and analyzed student experiences' ($n = 69$) and conclude that:

- DFNs can be easily assembled using existing and easily available "off-the-shelf" hardware and software, at a cost of approximately €600 per unit. We use a field-proofed iPad 9.7 inch with a range of applications, most notable the FieldMove app.
- The majority of the respondents (80%) had no previous experience with the DFN, and only one quarter owned a

tablet. Nonetheless, a brief training session was sufficient to make all students familiar with the DFN.

- The overall usability of the DFN was positive, with a spread from 1.9 to 2.9 (on a 1–6 progressive scale, with 1 the highest grade) reported from the five courses analyzed.
- The respondents suggest that while battery capacity and cold fingers are challenges, there are no obvious impediments to utilizing the DFNs in the Arctic environment, especially if polar adaptations are included.
- Examining the student responses and the delivered FieldMove projects, we note that the geo-referencing of notes, images, and structural measurements is the main benefit of the DFN. As such, we consider the DFN a complementary tool to improve students' spatial thinking skills, particularly at large, basin-scale, geological field excursions.

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