Managing Product Development and Integration of a University CubeSat in a Locked down World

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Abstract—**In this article, we describe how digital collaboration tools used during lockdown require new approaches to project management and systems engineering based on the action research case study of a CubeSat student team in Norway. The COVID-19 outbreak affected the whole world during the spring of 2020. Governments reacted by locking down countries and telling people to stay at home, and the university asked the students to work from home. Little previous research was found on managing virtual student teams, especially when not as initially planned. In this situation, many management tasks proved to require more effort than usual, such as managing team members, helping maintain work/home-balance for team members with families or focusing when working from home, and ensuring motivation and on-time project deliveries. The lockdown resulted in an increase of GitHub traffic on the software product. Reasons for this include (a) needing to commit software before the CDR, (b) strengthening of feeling that Github is a platform to work together in when the offices were closed, or (c) maturity of design in general increased contributions to code. All hardware integration efforts were put on hold, but team members expressed that they had time to focus on documentation. In a non-lockdown situation, they would not have done this because of prioritizing "hands-on" work. This may be beneficial in the long run, especially for onboarding new members to the team. Management of a team during lockdown includes evaluating and improving the technical infrastructure necessary for digital collaboration, managing the diversity of situations and other soft issues of a team, and managing schedule impacts both in the short-term and long-term. We found that project managers must make explicit efforts to maintain the project culture and motivation. For example, make efforts to replace the informal interfaces that take place in a co-located team with questions and round-the-table off-topic discussions in stand-ups and meetings. Furthermore, when large changes such as a pandemic happen, it is important to adapt and reinforce the team culture and norms. We also found that having an agile culture made the team more responsive to the change in working norms, such that there was a high willingness to "try out" the best way to lockdown-work.**

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1. INTRODUCTION

The recent Coronavirus (COVID-19) pandemic affected almost all countries across the world, and many students found themselves shut out from campus, from seeing their classmates and friends daily, and from traveling home to rejoin their families. Active research and student projects were affected in various ways, such as limited access to laboratory facilities to perform experiments and tests, or reduced mechanical workshop support, or restrictions on field tests. Additionally, the social processes were affected when it was no longer possible to drop by the coffee machine or visit someone's desk during the day for a chat or clarification of questions. Most projects saw the need to use digital collaboration platforms to a higher degree.

The main subject of this paper is to report on experiences of a team of students and researchers who were in the process of completing and testing their CubeSat payload when the pandemic completely reshaped their work environment. For many, distributed teams and digital collaboration are not new. However, when not planned for, the heavy reliance on digital tools can have a significant impact on project progress and team motivation. In global research projects, digital collaboration is sometimes the only means of communication available [1], [2]. Adding to the complexity is the management of a university CubeSat project, where project management, high turnover, transfer of knowledge, and ensuring mission success are recurring issues [3], [4], [5], [6], [7].

This paper is organized as follows. Section 2 provides a review of distributed and dispersed teams and digital collaboration, and introduction to some of the recorded problems CubeSat teams face. Section 3 describes the case study of the Hyper-Spectral SmallSat for Ocean Observation (HYPSO) project and organization, and the method applied for the study. In section 4, a timeline of events is described, including the Critical Design Review (CDR) meeting and results from a follow-up questionnaire. We analyze these events in section 5, with a focus on project management experiences and recommendations. Finally, we summarize the findings and give some lessons learned for managing a CubeSat team and design reviews with digital collaboration tools.

2. BACKGROUND

Distributed Teams and Digital Collaboration

Most organizations and projects have a mix of co-located and distributed or dispersed team members. In this paper, we define a distributed team for where there are both workers on-site in the office and workers in their home offices. A dispersed team is when these workers are spread out over a large area. Both types have significantly been researched in the setting of global teams, where the members can be in

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different places, time zones, and cultures [1]. Furthermore, team members may be temporarily dispersed in cases of traveling or home offices. The continuous evolution of digital tools has made the logistical aspects of managing distance collaboration simpler to address. However, there are "soft issues" that are important to consider as a manager, such as trust, relationship-building, frequency of communication, and social ties [1], [8], [9]. Most research papers we found discussed *planned* distributed or dispersed teams in businesses, we were not able to find much research on unplanned dispersed teams in academia.

For this team, the goal of the digital collaboration is to share information and to build the satellite collectively. Collaboration can be done by either working together on a task or having individual tasks that are brought together by another team member to deliver the end product [10]. Collaboration requires that there is a shared understanding and acceptance of the goals and deadlines. Furthermore, that the interfaces, both between subsystems, tasks, and people, are understood so that the system can be integrated to meet the goal.

To ensure the success of virtual teams, Kayworth et al. (2000) outlined 14 factors in four categories (communication, culture, technology, project management) needed, based on the case study conducted. These include having norms for communication and culture, training people in using digital collaboration tools, emphasizing continuous contact and communication, understanding the diversity of the team members, and expressing flexibility and empathy [2]. Having flexible project management is also essential for complex and knowledge-intensive projects, such as developing a spacecraft [11].

Verburg et al. (2013) reviewed the aspect of virtuality and types of technology needed to facilitate communication, management and challenges of dispersed teams, and the role of the project manager. Virtuality is related to the frequency and quality of communication and the means of facilitating this communication [1]. In the authors' review, they found that having trust between members and high-quality communication tools are necessary for collaboration. Furthermore, the project manager and organization should have clear rules of etiquette and policies such as muting the microphone when not speaking, or using video when speaking during real-time video meetings.

Virtual team management is enabled by having good organizational support [1], [8], [12]. Drouin et al. (2010) discussed the processes needed for virtual teams such as planning, interpersonal, communication, and collaboration processes. The authors highlighted the need for the team members to be "mindful of the potential differences between their daily reality and that of their foreign collaborators [12, p. 629]." While this case study includes few foreign collaborators, the team members are dispersed throughout Norway and have different daily routines and responsibilities.

A study on predominantly student virtual teams by Panteli et al. (2019) looked at students' experiences and reflections based on a dispersed global team located in United Kingdom (UK) and Norway.The teams studied had not worked together previously, but there was a plan and a structure for how the global virtual collaboration should be with supporting tools. The authors noted that many students had experiences with virtual collaborative platforms through the e-learning platforms, and that some students have used these platforms for teamwork previously. They found that having leadership was critical to success, and to agree to and understand that "norms needed to facilitate virtual team success [10, p. 795]."

The exchange of information and building organizational knowledge is a challenge with co-located teams, which can be more present in dispersed teams [8], [9], [13], [3]. Cramton discussed the types of information problems present in dispersed teams and categorized them into (1) failure to communicate contextual information, (2) difficulties in communicating the salience of information, (3) unevenly distributed information, (4) differences in speed of access to information, and (5) interpreting the meaning of silence [13]. Olaisen and Revang highlight the need for knowledge sharing and knowledge quality, based on the exchange of information combined with "experience, context, interpretation, and reflection [8, p. 1442]."

CubeSats

A CubeSat is a small satellite consisting of cubes, called "units," of 10 cm x 10 cm x 10 cm. The concept was conceived in the early 2000s by professors Puig-Suari and Twiggs [14]. Over the years, the CubeSats have grown from being university educational toys into carriers for versatile scientific instruments and businesses [15]. CubeSats now do a variety of missions, such as communication systems [16] and Earth observation [17]. The size of a CubeSat is diverse. Multiples of units can be combined, for example, into popular sizes of 2, 3, 6, and 12 unit satellites. There is a growing CubeSat community internationally, where businesses, academic, and research institutions together drive the technology onwards [18]. Projects can procure hardware, software, and services from a multitude of providers. Many CubeSat projects combine Commercial-Off-The-Shelf (COTS) subsystems with in-house developed components. Teams can make decisions to buy what they can or make what they need.

The research on project management and systems engineering in academic CubeSat projects highlights issues such as: ensuring continuity when there are high turnover and frequent exam periods [4]; project management and team structure [3], [4], [5], [6]; transfer of knowledge [7]; balancing academic work and satellite building [19] and; ensuring mission success [4], [5].

University CubeSat projects are usually constrained by time and low budget, and are dependent on thesis work by students to complete. There is little or no possibility to engage outside consultants to fill knowledge gaps. Alminde et al. (2005) recommend having Ph.D. students or other long-term resources manage the project, to ensure some continuity and knowledge transfer when the students leave. Furthermore, there must be an explicit effort to "make the students feel like part of a team [4, p. 13]."

Berthoud et al. (2019) conducted an in-depth comparative case study of 3 universities with multiple successful CubeSat missions. Their study showed the importance of having experienced staff leading the initiative, a limited development cycle, passionate students, balance the mix of curricular and extra-curricular work, using version-controlled repositories for managing information and project artifacts, and to emphasize testing. The authors also mention that there are different approaches to formal design reviews and knowledge management, where some have specific processes they follow, while others simply have design reviews and encourage team members to record the design in the various repositories [7].

Ensuring a good design requires broad knowledge and ex-

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perience. If there is a system and culture for knowledge management, the problem of high turnover is lowered. Furthermore, it is easier for project management to ensure that there is progress in the project and that non-conformances and product development issues are taken seriously. Formal design reviews are used as a tool to facilitate and encourage documentation of knowledge and to motivate project team members and stakeholders to accept a design and its decisions as a whole. Typical design reviews are Mission Design Review (MDR) and Preliminary Design Review (PDR) [20]. These reviews are not as common for academia, where projects are run “ad hoc” towards a prototype or proof-of-concept. However, it is the authors’ impression that many CubeSat projects follow *some* systems engineering principles for product development, such as defined milestones or gateways [5], [7]. Additionally, many teams attempt a controlled verification and validation approach to ensure that the satellite conforms to launch vehicle requirements. A recent study [21] highlights how the CubeSat projects classified as “Crafters — characterized by *Streamlined practices, experimentally developed*” have a higher rate of success than “Hobbyists — characterized by *Ad hoc practices*.”

3. CASE STUDY

CubeSat Team

The CubeSat team at Norwegian University of Science and Technology (NTNU) SmallSat Lab has been developing a mission with a 6U CubeSat since 2017, called HYPSO, with a scheduled (prior to pandemic) launch in Q4-2020. The satellite has a dual purpose: (1) to deliver oceanographic data to end-users (mostly scientists), and to (2) build competence at NTNU to enable fast development of scientific instruments for deployment in CubeSats or autonomous assets.

There is some previous history of building CubeSats and other space engineering products at NTNU, which has resulted in course credits and theses being produced. However, NTNU has had no successful missions to date [22]. The HYPSO CubeSat is the first satellite to be built at the university in recent years, and at the onset there was little knowledge in the faculty about the practicalities involved in building a satellite. The past three years have focused on building both competence and project culture, as well as developing the HyperSpectral Imager (HSI) payload from a Technology Readiness Level (TRL) of 3 to TRL 7.

Organization— The HYPSO project team consists of 5–6 Ph.D. candidates and 20 students writing their Bachelor and Master theses. The team has a project manager and multiple group leaders (all Ph.D. or Post.Doc. students) that are responsible for following up on the design of their subsystems. This includes following up the Bachelor and Master students. The students join the project in either September or January, and most leave in early June. It is challenging to ensure proper transfer of knowledge while simultaneously fulfilling the individual research goals. A thesis does not necessarily include the documentation necessary for someone else to continue the space engineering project. Most of the team members do not have any previous experience with configuration control, formal documentation, project teamwork, or documenting work. However, most of them join the project because they are passionate about space or their specific thesis’ tasks. The team members seem motivated to try new techniques and methods to make the project work better.

There has been confusion about design decisions, issues of knowledge management and information flow, lack of clear follow-up and commitment among the project team, and an ad-hoc review process since the project started up in 2017 [3]. In order to improve the project teamwork, it has been suggested to introduce Systems Engineering (SE) and Project Management (PM) methods and tools [23].

Methods of Collaboration—The project team members are encouraged to work on their thesis and the satellite in the lab area, to facilitate concurrent engineering and communication. The main communication channel is **Slack**[1] [24], where day-to-day messages and discussion take place in different topical channels.

No formal processes have been implemented, but a team agreement made in January 2018 stated that all decisions should be documented and that there should be formal reviews and gateways based on tailored European Cooperation for Space Standardization (ECSS) review recommendations. Two reviews had been conducted in the project prior to the introduction of a formal documentation management tool. These have been reported and discussed in [3]. The main findings from this analysis were that the formalized review processes help; using cloud services that support concurrent work on documentation lowers the barriers to contribute to the knowledge base; having a format to provide review comments encourages feedback, but there is a lack of structure and system in the documentation and traceable requirements and follow-up from feedback. The previous reviews have used either questionnaires or spreadsheets to collect feedback.

The digital project management tools have included communication through e-mail, documentation and meeting notes wiki with the possibility of assigning action items, cloud-based spreadsheets and documents, and software code configuration control through **GitHub**[2] using GitHub flow [25]. An automatic Jenkins[3] [26] unit test is run on the master branch of the software on an x86 architecture[4] every night for regression testing of new software changes. The process of software development is shown in Figure 1.

Prior to the events following the COVID-19 outbreak, the team was accustomed to using online meeting tools for regular weekly meetings, ad hoc meetings, and daily stand-ups, as one or more team members often were traveling, working from home or staying abroad.

Method

This paper is based on the method of *action research* through an *exploratory case study* [27]. In action research, the authors themselves are active participants in the project and can influence the team through their behavior. We have chosen the method of exploratory case study because it allows for the discovery of unanticipated behavior and phenomena. The COVID-19 pandemic was an unforeseen event that resulted in a new working environment for the team, which had not been anticipated when the research was started.

The research questions addressed by the paper are:

- **RQ. 1:** What methods and modes of interactions in a university CubeSat research project exist, which methods and

[1] A business communication software
[2] A system for software development version control
[3] Open-source automation server used for automatic testing of software
[4] Instruction set architecture, most computers use this architecture

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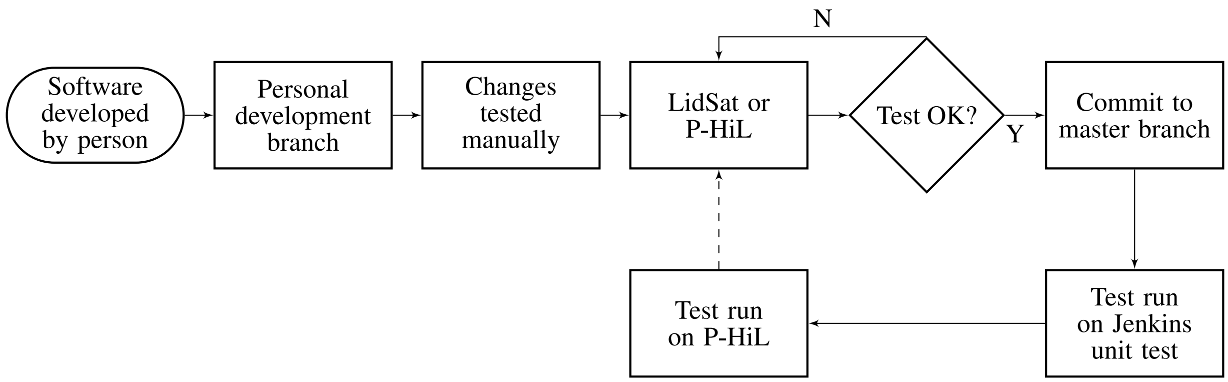

Figure 1: Software development process. Code is exchanged in the flow.

modes work well, and why do they work well?
- **RQ. 2:** How can formalized design reviews improve CubeSat development in a university setting?
- **RQ. 3:** How can project managers run CubeSat research projects successfully when the team is distributed?

The sources of data include (1) digital artifacts in communication channels such as **Slack** and email, (2) reflections from telephone calls and video conferences, (3) feedback from team members through questionnaire, (4) digital artifacts in documentation system, (5) digital design artifacts.

Limitations of the study: The case study is limited to the HYPSO team at the university, which is a small sample size, so that it is difficult to generalize the findings outside this context. The context matters and different countries have taken other measures to the COVID-19 outbreak, so the findings may differ at other CubeSat teams in a different sociotechnical context. Furthermore, as a qualitative study, the findings are based on the interpretations of the authors, which may be interpreted differently by other researchers. However, the findings are in line with other research reviewed, and some generalization and lessons learned can be extracted from the case study and findings.

4. EVENTS

This section will detail the sequence of events and the effects these had on the team and the road to digital collaboration. Figure 2 shows the timeline of national events and for the team.

Hardware-in-the-Loop

While the Jenkins unit testing of the software process provides regression testing of software changes on x86-architecture, it is limited to the unit tests specified by the team. Not all software developed is hardware-agnostic (meaning that it has to run on the target hardware of the payload to function), and it is necessary to have hardware-in-the-loop (HIL) setups to test the software developed.

A HIL-setup was developed and set up starting in January and was almost completed by mid-March. The HIL-setup consists of two systems, called P-HiL (Payload Hardware-in-the-Loop) and LidSat, shown in Figure 3. The P-HiL-setup has been built to enable fast, repeatable, and automated testing of the HYPSO software on the development x86 hardware, which is similar to the target hardware. The purpose of the LidSat is to test the payload software and hardware, in addition to interface with the FlatSat consisting of the other spacecraft subsystems in Vilnius, where the supplier is situated.

Campus Lockdown

The team received the notification that the campus would be closed down on the morning of March 11^{th}. Things happened rather quickly, and some of the team members left campus before the group leaders could talk with them. Many of the students left believing that they would be allowed back on campus in a short time. The first set of regulations asked all students to leave campus. Later on, the regulations were expanded to include all employees who could work from home should work from home. There was an exemption for lab personnel so that essential functions could be maintained.

While some students were developing software, many were working on integration tests in the HIL-setup, and other tasks that require hands-on activities with the hardware. The leaders decided that the students who were working with hardware could bring some copies home with them, although the number of sets was limited. Still believing that the lockdown was short-term, the students were asked to focus on CDR documentation, and their theses work.

Work-from-home adjustment

No students showed up for the first all-digital stand-up, partly because they were not used to using online meeting platforms for stand-up (it used to be in a room), so they forgot about it, and partly because the online meeting platform was not compatible with their operating system. The project manager changed online meeting platforms to find something that worked better with a large team on different operating systems. Considerations included operating system diversity, bandwidth (how the meeting platform could handle changes in bandwidth and adjust the video and audio streams seamlessly), options for interaction, options for viewing. The team members were all favorable to the trialing of multiple platforms until settling on the platform that was most suited to the needs.

Team members reported that it was challenging to manage the interruptions caused by having to take care of kids who could not go to kindergarten or having to share office area with their partner in their homes. Additionally, some reported issues with broadband speed when there were multiple people in their homes needing video-calls or similar. The university also had not prepared for such a demand for their Virtual Private Network (VPN) service and did not have the

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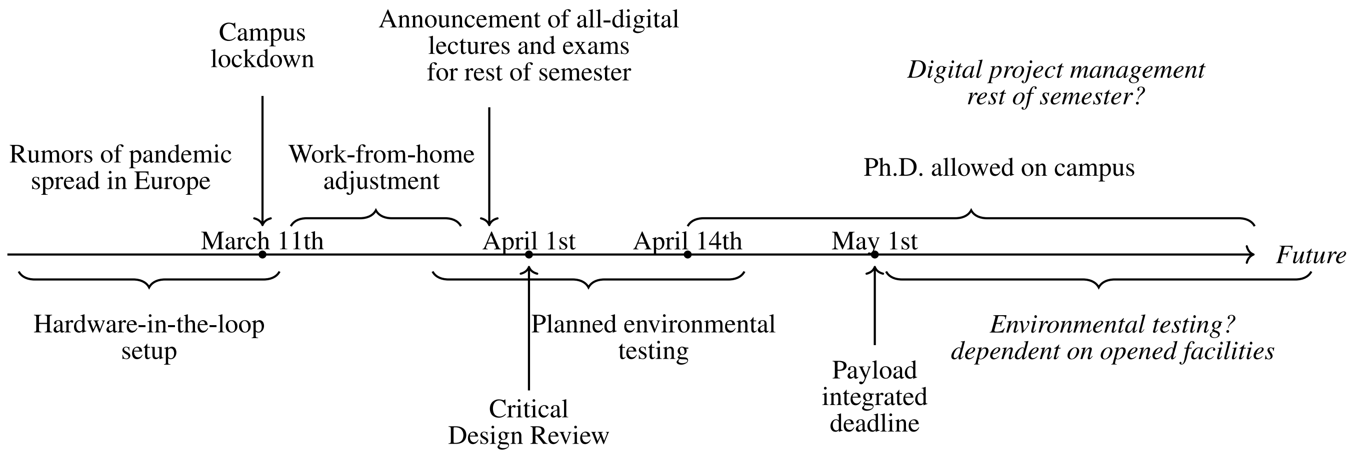

Figure 2: Timeline of events. Text below timeline are planned events, while text above timeline are events related to pandemic and the team's adjustments. Text in italic are open-ended events.

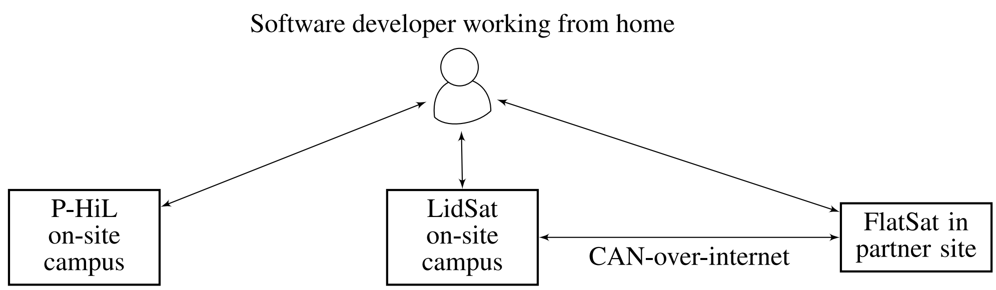

Figure 3: User interface to HIL-setups over internet. CAN=Controlled Area Network protocol used as communication protocol on-board the satellite.

bandwidth to support the requests from everyone at once, so students and employees were encouraged to limit the use of VPN. Some university-resources, including the test and development setups in the lab, are unavailable without a VPN-connection. The capacity of the VPN system was gradually increased over a few days.

Announcement of all-digital lectures and exams for the rest of the semester

At the end of March, the university administration announced that there would be no more scheduled activities such as lectures or exams on campus. All these events should take place digitally or be canceled. For most students, this meant that there was no reason to stay near campus, and some left to go home to stay with their parents instead.

Critical Design Review

The CDR had been planned to happen as a document review process supported by a professional review management tool tailored for the European space sector, ending with a collocation meeting planned to take place on campus. This was changed to being an university-hosted Zoom[5] [28] meeting. The review process was conducted as close as possible to the process recommended by the European Space Agency (ESA) shown in Figure 4. The review team was asked to provide Review Item Discrepancy (RID)s ahead of the collocation meeting so that the HYPSO project team could categorize them into Major and Minor. The collocation meeting focused on discussing and clarifying Major RIDs.

Multiple tools were tested before the design review collocation meeting. The main requirements for the tool to be used were: (1) Good handling of reduced bandwidth with multiple users; (2) Available and functional on multiple operating systems; (3) Possibility for meeting leader to mute/un-mute participants; and (4) Providing participants a *good feeling of belonging*. The last requirement was essential to ensure active participation in the meeting and is dependent on both the meeting leader's inclusion and the tool itself. All tools were tested with more than 10 participants prior to the meeting. In addition to fulfilling requirements (1)-(3), Zoom was chosen because of its "gallery mode" where you could view up to 49 participants in one grid, more than any of the other tools. Furthermore, the possibility to create "breakout rooms" allowed for subsystem discussions during the meeting.

The meeting's duration was from 08:30 to 16:00 on the first day, and from 08:30 to 11:00 on the second day. The first day's agenda started with an introductory round of all participants where they showed video and gave a short introduction. Following that, the mission and project status were presented before a more in-depth presentation of each of the topic areas such as software, hardware, and operations. There were breaks every 90-120 minutes. After the presentations, the participants were divided into five topic groups where the HYPSO team acted as meeting leaders. These groups were "sent" to breakout rooms where they discussed each topic and associated RIDs for approximately 45 minutes, when the review team was "rotated" to go to the next topic

[5] A video and web conferencing tool

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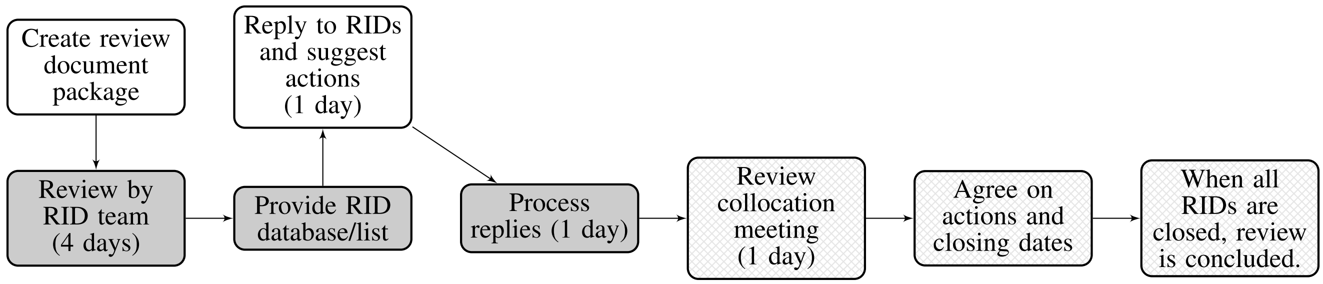

Figure 4: ESA recommended review process. The grey blocks are performed by the review team (RID team), consisting of professors and external reviewers that have experience with space systems, while the white blocks are performed by the project team. The cross-hatched blocks are common.

and associated breakout room. After all the RIDs had been addressed, the HYPSO team agreed on action items and deadlines together with the review team for closing the RIDs. At the end of the first day, the meeting leader asked each topic leader to summarize the findings and described the agenda for the second day.

The second day, the focus was on estimating the probability of meeting the mission and identifying the major unknowns and risks for each topic area. This helped to prioritize the action items. Finally, the meeting concluded with a summary of prioritized areas, and no new meeting was announced.

A voluntary questionnaire was sent out to the participants of the review after the meeting concluded. Out of the approximately 44 participants, 38 responded, $N = 38$ where N equals number of respondents. The total age span was 21-68, and 66.6% of the respondents were in the age group 21-30. This corresponds with most of the HYPSO project team, of which the vast majority are in that age group. The sample size of other age groups was small, and no clear correlation between age and answers could be found in the analysis of the results shown in the paper.

Most of the respondents participated in the meeting using a computer, evenly distributed between Windows, Linux, and Apple operating systems. Some respondents indicated dual-use with a phone as well. The respondents indicated previous experience with different types of video conference tools, including Zoom, as used during CDR. All respondents indicated that they used audio continuously or intermittently, while 26% responded that they did not use video during the meeting.

The meeting was evaluated on a Likert-scale and with an option to add "Other comments" where the results of Likert questions are shown in Figure 5. There is a high degree of agreement that the meeting's objectives were understood and met, that the meeting stayed on-topic and that the agenda was clear, and that in case RIDs had been submitted, they were answered and things were clarified. More than 50% agree that people spoke less than normally, and that they were more to-the-point in their responses.

The usage of the professional review tool for managing the documentation and review was evaluated on a Likert-scale shown in Figure 6 and with an option to add "Other comments". There is a strong agreement that the RIDs were helpful, almost 50% responded neutrally if they would use the tool again.

The usage of Zoom for managing the design review was evaluated on a Likert-scale and shown in Figure 7. The respondents were also invited to provide further comments in an "Other comments" open-ended form. More than 90% responded that they would use the tool again and that the option to create breakout rooms was helpful. Close to 95% responded that it was easy to install the tool and join the meeting, as well as being able to hear and see the other participants well.

Planned Environmental Testing

The planned environmental testing at the end of March and the beginning of April did not take place because of national travel restrictions and because of test facilities going into lock-down. Furthermore, some components for finalizing the payload had not been ordered yet, and suppliers were not sure when they could provide them. The planned environmental testing was critical to have enough time to verify that the payload would survive launch and operate in a space environment. The canceling of environmental testing meant that the payload was not fully verified to CDR.

Payload Integrated Deadline

The HYPSO team had planned to have an integrated payload proto-flight model ready for shipping to the spacecraft supplier by May 1st. Because the environmental testing did not happen as planned, this had to be delayed.

Ph.D. Allowed on Campus

The university slowly started opening up for PhD candidates to access the laboratory facilities on a case-by-case basis with limited hourly access. This has enabled resuming some integration activities but with a greater need for planning.

5. Discussion

In this section, three topics of discussion are addressed: (1) Technical infrastructure to enable digital collaboration, (2) Sociotechnical issues and project management, and (3) Schedule impacts.

Technical Infrastructure to Enable Digital Collaboration

This section will discuss some of the tools used to support digital collaboration and how the usage changed, if applicable, during the lockdown and working from home.

The basic challenges of interoperability for tools and access to broadband were most prominent in the first phase (Work-from-home adjustment in Figure 2), and although important to consider when managing distributed teams, will not be

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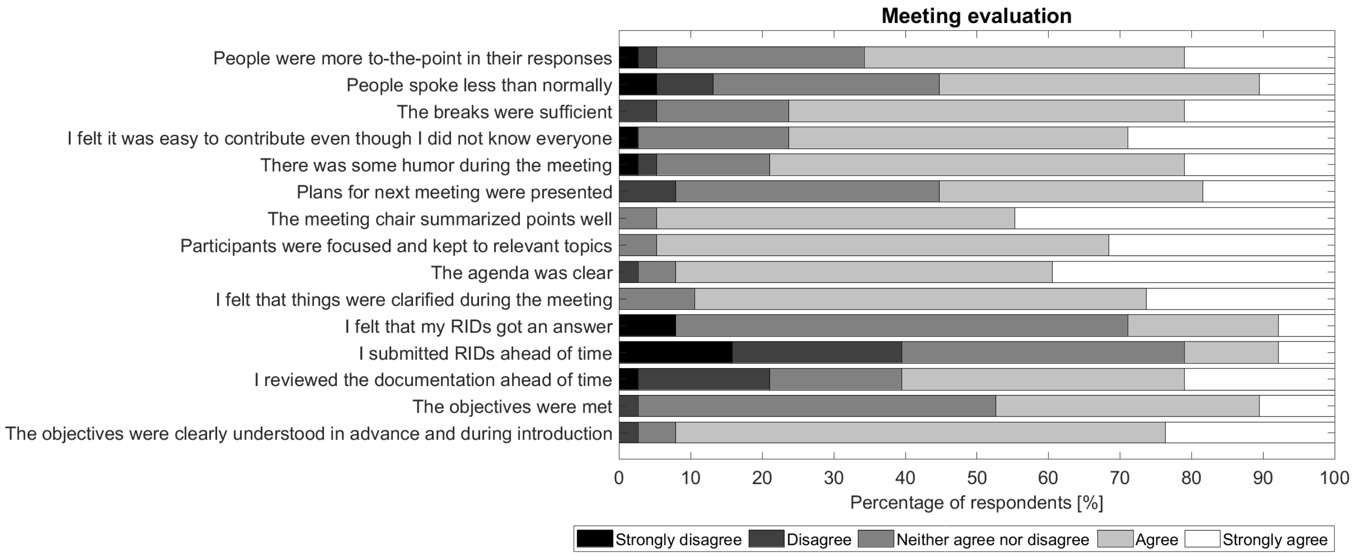

Figure 5: Overall results from meeting impressions.

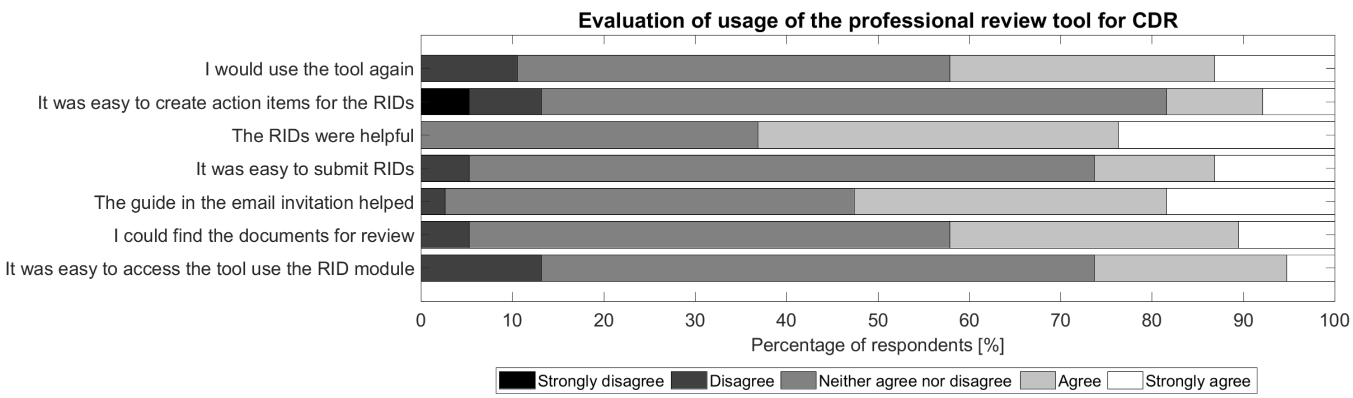

Figure 6: Impression of using the professional review tool for the review and during the meeting.

discussed in detail in this paper.

Software development process. The NTNU team uses GitHub to manage the different software repositories. According to the statistics, the traffic of new software contributions ("new commits") increased after the lockdown, both from existing contributors and with new contributors. There may be several reasons for this, such as (a) needing to commit software before the CDR, (b) strengthening of feeling that Github is a platform to work together in when the offices were closed, or (c) maturity of design in general increased contributions to code. The workflow shown in Figure 1 and GitHub flow [25] are mostly followed.

The main part of the code consists of two individual repositories; one is encompassing the Linux file and operating system for the payload, as well as the Field Programmable Gate Array (FPGA) bit-stream. The second repository holds the rest of the payload software, which is the camera control and processing. Most of the team members contribute to the second repository, while the first has fewer contributors. There have been some problems ensuring alignment of dependencies between the repositories, leading to a non-functioning state of the head of the master branch of the second repository. The root cause was a lack of testing the software changes on feature branches between both repositories before merging them to the master branch[6].

A "broken" master head had not happened before, and the increase in traffic in the repositories increased the likelihood of it happening. At the same time, when the team was all working in the same office, the development was more coordinated because members had continuous informal discussions, so there was a lower likelihood of mismatching between repositories and increased likelihood for testing because the HIL-setups were in the room.

Zoom as a meeting tool. Zoom proved to work well as a platform to execute the CDR. No major technical challenges were encountered (from the organizing perspective). Com-

[6] From GitHub flow: the master branch is the software ready for deployment.

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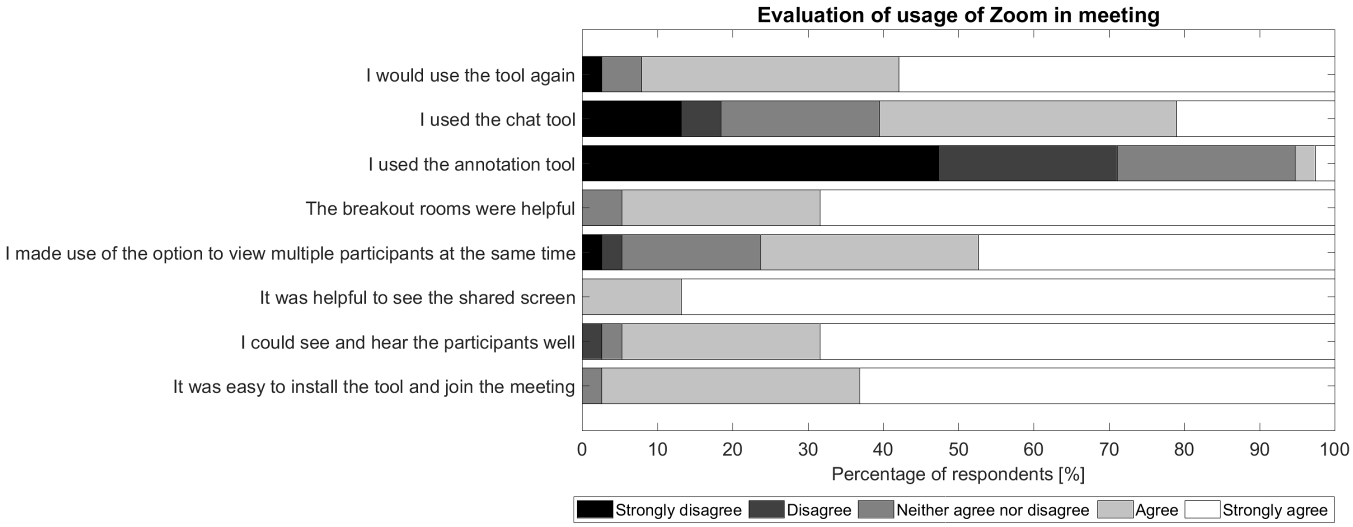

Figure 7: Impression of using Zoom for the meeting.

pared to a physical co-location meeting, the time control was harder to enforce, when presenters went over their allocated time. This was also given as feedback in the questionnaire. During the more interactive breakout room sessions, features such as screen sharing, remote access to other participant's screens, and annotation tool were used. The meeting leader could easily "visit" the smaller groups and move participants between rooms when needed.

Using a professional review tool. The results in Figure 6 summarize that although the tool's functionality is useful, some training is needed to access its functionality. There was no difference in responses in terms of age groups. The tool allows for traceability from documentation to review data package to RIDs to action items that can be assigned to project team members and followed up by the project manager. This adds to the explicit knowledge of the project, which is helpful in CubeSat teams where there is a high turnover, as mentioned earlier. By having design reviews and recording discrepancies and associating action items, the team can find the "paper trail" of task prioritization and design choices. For example, if the version of design lacks a particular analysis, this can be addressed in a RID, which is then associated with the action item "Do thermal analysis on mechanical structure" which in turn can lead to an update in documentation (a new issue or revision). These steps can be traced in the tool, reducing some of the knowledge loss of decisions that can be seen in CubeSat teams [22], [3].

In summary, it is critical to pay attention to the following aspects of technical infrastructure:

- Ensure digital collaboration infrastructure in terms of interoperability.
- Allow time for people to adjust to the changes.
- Allow time for people to become accustomed with using the software development process.
- Use videoconferencing tools where you can see all participants to increase sense of belonging.
- Use breakout rooms in videoconferences to facilitate smaller discussions.
- Use a professional review tool to provide traceability for design and actions, which helps knowledge management in teams with high turnover.

Sociotechnical Issues and Project Management—The technical tools and processes assist the development of the spacecraft, but the team needs to execute these processes and use the tools. We call this a *sociotechnical system* [29]. This section will discuss some of the sociotechnical and project management challenges and give suggestions for best practices.

The main tasks of a project manager are to manage the resources, the schedule, and the scope of work. The project management of a student-based CubeSat team is challenging in itself [4], [5], [6], and in a time of national crisis and high uncertainty, even more so. When the campus lockdown happened, most people believed it would re-open shortly. Both the team members, the group managers, and the project manager were privy to the same information given from the university administration. The uncertainty of the situation made it difficult to plan, and over time the gravity of the pandemic made it clear that it would be a semi-permanent change to how we function as a society.

Project management must enable and support the use of the technical infrastructure and motivate team members to follow the project processes and development flows — the project norms. The project manager must also cultivate the team cohesiveness and culture, and to continue this during the lockdown. The project norms and culture help the team feel connected [1], and these must be maintained and updated when the team becomes distributed. This means communicating the flow (as in Figure 1) and following up frequently with the team members until it becomes a part of the team culture. When there are external changes, such as COVID-19, this should be re-emphasized. We experienced that the large change of the lockdown introduced caused people to partially "reset" the way they worked, and there was a risk of going back to ad hoc practices and not follow the now-established processes and development flows. Furthermore, the project manager must be a champion of using tools for digital collaboration, especially when they are difficult to use,

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as with the professional review tool, where respondents indicated that the user interface was not optimal [30], [31]. The tool has since been improved with new releases to improve the user interface, and we assume that a new review and survey will give a different feedback. Low overhead and low personal investment are important to ensure that people will take systems into use unless championed by management, or required by management.

We reported on the benefits of being in the same office area in [3], because it allowed for fast closure of issues and increased knowledge exchange and flow of information [13]. While not measured quantitatively, there was a high frequency of informal discussions and conversations when the team was co-located (based on observation study). There were also regular coffee breaks, lunches, dinners, workshops, and birthday celebrations — all to increase the team cohesiveness and lower barriers to encourage interactions. There was an increase of short video-calls or phone-calls in the first few days after the lockdown, because team members had a need to clarify things, and because it was nice to stay in touch with the people whom they were used to seeing on a daily basis. However, some members did not show up for the daily stand-ups, as mentioned earlier. There was also a lack of communication on Slack and e-mail by the same members, and some tasks were getting delayed. While technical difficulties may be one reason, not feeling that they are a part of the distributed team, or that other stress factors make the project work less important and urgent can also be reasons for this. The project manager made sure to continue having stand-ups every day and also reaching out to team members individually to check in and provide feedback. This takes time and requires commitment from the project manager. After the Easter holidays and Labor Day long weekend, the project manager spent a portion of the weekly meetings to talk about non-work topics, which helped fill the gap of the missing informal coffee breaks.

The project manager is also responsible for managing the diversity of the team members, in terms of the diversity of their daily lives and schedules, and the external factors affecting their productivity. This means that the project manager must take an active role in managing and tailoring the tasks to fit the changes caused by the lockdown. For example, by adding resources to developing subsystems or changing deadlines and reducing inter-dependencies of tasks to enable more distributed work [2].

The COVID-19 outbreak caused the team to become distributed, affecting the information flow. On the one hand, when being co-located, people also assumed that knowledge was shared and implicit. On the other hand, when the team is distributed, all information must be made explicit, and people are aware of this, which may be one of the reasons for the increased traffic on GitHub. There was also an increase in the use of discussion channels on Slack, where everything is stored for future reference. While it is too early to conclude, the distributed team structure necessitates more explicit knowledge and having multiple information exchange channels [2]. This can be helpful for off-and on-boarding when the current project team leaves at the end of a semester, and a new one arrives after summer. If the lockdown continues, it will be interesting to see how to successfully on-board a fully digital distributed team.

The risk management process of the project had not identified being locked out of campus as a potential risk, neither in the short-term nor the long-term. The country had not been strongly affected by the previous recent pandemics (Severe Acute Respiratory Syndrome (SARS) in 2003 or Middle-Eastern Respiratory Syndrome (MERS) in 2015), and while a pandemic had been identified as a risk by the Norwegian Directorate for Civil Protection [32], this was not included in the project risk assessment. Although it cannot be expected that a university-based project should take large national risks into account. At the sime time, some of the pandemic impact could have been identified with corresponding mitigation actions. The risk acceptance and risk understanding impact the risk management. As a society on a macro level, and as the project team on a micro level, there might have been a risk aversion against a pandemic since we did not take it into account. Furthermore, we did not fully understand the risk and what it would mean to the project and our daily lives. The project risk management is conducted in the professional review tool and some of the impacts such as "R-1: delays in supply chain", "R-2: lack of access to testing facilities", "R-3: team members not present in on-site" or "R-4: HIL-setup not available" were addressed as separate risks (R-1 and R-3), but the risk of all of them happening at the same time was not handled which is an avenue for future improvement for university CubeSat teams. Furthermore, R-1 was assessed to have a low likelihood since the supply chain was mostly in-house, and the risk of the internal workshop not being available was not considered. Similarly, R-3 had been assessed as low impact and low likelihood because some measures had been taken (regular meetings with videoconferencing tools, the commitment of team members to be on campus), and it seemed probable that the team members would be present on campus since that is regular mode of operation for the project members. This can, in part, be attributed to *availability bias* or the *availability heuristics*, where our risk assessment is influenced by how available our memory of events is. For example, if something has happened recently that had a strong impact, even for a short period, we would remember it vividly and might assess it as having a high probability and impact — even though it objectively did not. While the virus spread in China brought up in the weekly meetings prior to the campus lockdown, we did not consider that we might be asked to work from home. However, given that Norway had not been strongly affected by the previous pandemics, our biases downplayed the risk likelihood and impacts. In the case of R-3, because it had not been a problem lately, we assessed it as low probability and low impact because we could not imagine it happening.

For project managers, we highlight the following lessons learned:

- Make an explicit effort to replace the informal interfaces that take place in a co-located team with questions and round-the-table off-topic discussions in stand-ups and meetings.
- Distributed team members have diverse daily lives, and this diversity must be managed by being flexible and by regular individual communication with team members.
- It takes more time and commitment from the project manager to follow up distributed team members than when co-located.
- When large changes such as a pandemic happen, it is important to adapt and reinforce the team culture and norms.
- Having an agile and flexible mindset can help mitigate the impacts of risks not identified.
- Cognitive bias' will affect the risk acceptance and risk understanding of team members, and knowing this helps to manage the risks.

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Schedule Impacts

The COVID-19 outbreak caused an overall delay to the project, partly because of lower productivity, responsiveness in the supply chain, and because of the availability of testing facilities. This section will discuss some of the main issues and impacts on schedule, and some suggestions for managing the schedule of a university CubeSat project based on the experiences had.

There were both short-term and long-term impacts on the schedule from the COVID-19 outbreak. In the short term, it meant little or no accessibility to testing facilities, and slower delivery of parts because the supply chain was operating at lower speed due to various restrictions. Longer-term effects come further down in the supply chain, such as deliveries of components, electronics, raw materials for machining, and less dependable freight of components. A lesson learned from the supply chain management, also applicable to university student projects that cannot afford the long delays that larger corporations might have funds for, is to manage the risk of having a *Just-in-Time* (JIT) supply culture, which is strongly affected by pandemics [33], [34].

The delay of delivering a verified and integrated payload meant that the timeline for payload-spacecraft integration must be shortened, increasing the risk of the mission. Furthermore, a new approach with remote functional testing had to be planned in case the team members could not travel to the testing facilities. This added more work to the software development team, which was challenging when most of the team members were supposed to reduce their project work and focus on writing their master theses.

Project managers of university CubeSat projects should consider the following:

- Continuously managing the project schedule and communicating it to the team — making sure that there is an understanding of interdependencies of tasks.
- Be flexible and re-prioritize tasks when the students go into thesis writing phase — focus on few and well-defined deliverables for project.
- Work together with mission responsible to adapt mission objectives to delays in development causing a more compact schedule.
- Consider the JIT supply culture of the world and plan for mission adaption if components and functions cannot be delivered on time.

6. CONCLUSION

The findings from this study provide some best practices and insights that can be useful for distributed and dispersed engineering teams. While the case study focused on an academic context, the results and recommendations are relevant for industry professions also. Especially, we want to highlight the importance of project managers to manage the sociotechnical aspects of teamworks, ensuring that practices and culture are cultivated, and paying attention to managing diverse situations in a lockdown. The study looked at both normal project work and at conducting project milestone, the Critical Design Review. We found that when building a hardware-software system, in this case, a CubeSat, it is important to consider the following aspects: (1) technical infrastructure to enable digital collaboration and ease of working-from-home; (2) sociotechnical issues regarding collaboration and team cohesiveness are prone to influence by factors outside the project; (3) and compound schedule impacts forced by the pandemic may be present in future projects and need to be addressed by the project and risk management.

Addressing research questions. In response to RQ. 1, we found that there are multiple modes of interaction present in a university CubeSat team, both formal and informal modes. The formal ones include regular stand-up meetings and group meetings, while informal ones are communication on Slack, e-mail, on GitHub, coffee breaks, in the co-located working area, etc. After the lock-down, it became clear that the importance of Slack and GitHub increased, and that these also function as information flow channels [13]. Furthermore, including more off-topic and informal discussions in formal meetings should be facilitated by the project manager, to build a digital informal communication culture to replace the co-located communication channels we used to have. These interaction methods and modes work well because they each have their purpose — Slack for clarifying and discussing architectural or system topics, GitHub for specific software issues, meetings for larger "face-to-face" discussions that end up documented in GitHub or meeting notes. This is in agreement with Kayworth et al. (2000) which identified having multiple communication channels for different purposes as a success factor for virtual teams [2].

Having formalized design reviews (RQ. 2) helps ensure the traceability of design and design decisions. They also act as a team cohesiveness event in the way that there is a common understanding of the design and the way forward to reach the project goals and objectives. Usage of the professional review tool greatly helped documenting the traceability from design to actions and back to design again, and makes it is easier to manage the design knowledge for future team members. By this, we propose that having professional tools can be helpful for CubeSat teams, but that they require a champion and support from project management to be utilized and maintained.

In response to RQ. 3, these are some lessons learned for project managers of CubeSat projects in a distributed team setting. Firstly, it is important to choose digital collaboration tools and establish norms that fit the project phase and people, and to champion these continuously. For example, introduce work-from-home options and the collaborations tools even if there is no lockdown, to accommodate working parents, or teachers on sabbatical. Secondly, as a project is a sociotechnical system where people and processes matter, the project manager's most important task is to balance progress with empathy for individual situations. For university CubeSat projects, this means understanding the diversity in the daily lives where many students may be all alone in the lockdown while others also have families they need to be with. Project managers need to make explicit efforts to maintain the team culture and facilitate the informal communication that happens naturally when co-located. Thirdly, project managers should work with the persons responsible for adapting mission objectives to fit the changing development schedule and tailor the schedule and project tasks for students to fit their curricular obligations (such as thesis writing). In summary, having a flexible or agile, project management is key to successfully leading distributed teams [2].

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Appendix

List of Software Tools Used

- **GitHub**: A system for software development version control
- **Slack**: A business communication software
- **Jenkins**: Open-source automation server used for automatic testing of software

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References

[1] R. M. Verburg, P. Bosch-Sijtsema, and M. Vartiainen, "Getting it done: Critical success factors for project managers in virtual work settings," *International Journal of Project Management*, vol. 31, no. 1, pp. 68–79, 2013.

[2] T. Kayworth and D. Leidner, "The global virtual manager: a prescription for success," *European Management Journal*, vol. 18, no. 2, pp. 183–194, 2000.

[3] E. Honoré-Livermore, "Cubesats in university: Using systems engineering tools to improve reviews and knowledge management," *Procedia Computer Science*, vol. 153, pp. 63–70, 2019.

[4] L. Alminde, M. Bisgaard, D. D. V. Bhanderi, and J. D. Nielsen, "Experience and methodology gained from 4 years of student satellite projects," in *2nd International Conference on Recent Advances in Space Technologies*, vol. 1. Turkey, Istanbul: IEEE Xplore, 2005, pp. 94–99.

[5] M. Cho, "Best practices for successful lean satellite projects," 2016. [Online]. Available: https://unisec2016.castra.org/index.php/unisec2016/unisec2016/paper/view/49/10

[6] J. Bouwmeester, G. Aalbers, and W. Ubbels, "Preliminary mission results and project evaluation of the delfi-c3 nano-satellite," in *4S Symposium Small Satellites Systems and Services*, 2008.

[7] L. Berthoud, M. Swartout, J. Cutler, D. Klumpar, J. A. Larsen, and J. D. Nielsen, "University cubesat project management for success," in *Conference on Small Satellites*, 2019.

[8] J. Olaisen and O. Revang, "Working smarter and greener: Collaborative knowledge sharing in virtual global project teams," *International Journal of Information Management*, vol. 37, no. 1, Part A, pp. 1441–1448, 2017.

[9] S. Jarvenpaa and D. Leidner, "Communication and trust in global virtual teams," *J. Computer-Mediated Communication*, vol. 3, 1998.

[10] N. Panteli, T. A. Hjeltnes, and K. A. Strand, "Learning to lead online collaborations: Insights from student-based global virtual teams between uk and norway," in *18th International Federation of Information Processing (IFIP) Conference on e-Business, e-Services, and e-Society (I3E)*, I. O. Pappas, P. Mikalef, L. Jaccheri, Y. K. Dwivedi, M. Mäntymäki, and J. Krogstie, Eds., Trondheim, Norway, 2019, pp. 785–796.

[11] R. Dove and B. Schindel, "Agile systems engineering life cycle model for mixed discipline engineering," in *INCOSE International Symposium 2019*, Orlando, Florida, 2019.

[12] N. Drouin, M. Bourgault, and C. Gervais, "Effects of organizational support on components of virtual project teams," *International Journal of Managing Projects in Business*, vol. 3, pp. 625–641, 2010.

[13] C. Cramton, "Information problems in dispersed teams," in *Academy of Management Proceedings*, 1997.

[14] H. Heidt *et al.*, "CubeSat: A New Generation of Picosatellite for Education and Industry Low-Cost Space Experimentation ," in *Proceedings of the AIAA/USU Conference on Small Satellites, SSC00-V-5*, 2000. [Online]. Available: https://digitalcommons.usu.edu/smallsat/2000/All2000/32/

[15] M. N. Sweeting, "Modern small satellites-changing the economics of space," *Proceedings of the IEEE*, vol. 106, no. 3, pp. 343–361, March 2018.

[16] Kepler, "Kepler's first ku-band satellite is in orbit," accessed February 2018. [Online]. Available: http://www.keplercommunications.com/blog/item/first-launch

[17] Planet, "Planet webpage," 2016, accessed April 2016. [Online]. Available: www.planet.com

[18] Small Spacecraft Systems Virtual Institute, "State of the art - small spacecraft technology," Ames Research Center, Moffett Field, California , Tech. Rep. NASA/TP–2015–216648/REV1, 2018. [Online]. Available: https://www.nasa.gov/sites/default/files/atoms/files/soa2018_final_doc-6.pdf

[19] C. D. Abadi and T. Bahill, "Product and process: an innovative approach for a student satellite program from the systems engineering point of view," in *15th Annual/USU Conference on Small Satellites*, 2001.

[20] Requirements and E.-E. Standards Division, "Space management: Organization and conduct of reviews," 2008.

[21] M. Swartout, "Cubesat mission success: Are we getting better?" in *2019 CubeSat Developers' Workshop*, 2019, Conference Paper.

[22] J. Grande, R. Birkeland, A. Gjersvik, S. Mathisen, and C. Stausland, "Norwegian student satellite program – lessons learned," in *68th International Astronautical Congress*, 2017, Conference Paper.

[23] P. Waswa and A. M. Madni, "A survey of space mission architecture and system actualization methodologies," *International Journal of Space Science and Engineering*, vol. 4, no. 3, 2017.

[24] Slack Technologies, *Slack*, San Francisco, CA, USA, 2020. [Online]. Available: https://www.slack.com

[25] GitHub, "Understanding the github flow · github guides," https://guides.github.com/introduction/flow/, (Accessed on 04/23/2020).

[26] K. Kawaguchi, *Jenkins software*, Software in the Public Interest, USA, 2020. [Online]. Available: https://www.jenkins.io/

[27] R. K. Yin, *Case Study Research and Applications: Design and Methods*, 6th ed. SAGE Publications Inc, 2017.

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[28] Zoom Video Communications, Inc., *Zoom*, San Jose, CA, USA, 2020. [Online]. Available: https://www.zoom.us

[29] W. B. Rouse, M. J. Pennock, and J. Cardoso, "Advances in sociotechnical systems," in *Advances in Systems Engineering*, J. Hsu and R. Curran, Eds. American Institute of Aeronautics and Astronautucs, Inc., 2016, pp. 35–64.

[30] G. H. A. Morton, "Become a project champion," *International Journal of Project Management*, vol. 1, no. 4, pp. 197–203, 1983.

[31] J. Pinto and D. P. Slevin, "The project champion: key to implementation success," *Project Management Journal*, vol. 20, pp. 15–20, 1989.

[32] Direktoratet for samfunnssikkerthet og beredskap, "Analyse av krisescenarioer 2019," Tech. Rep., 2019.

[33] L. J. Radonovich, P. D. Magalian, M. K. Hollingsworth, and G. Baracco, "Stockpiling supplies for the next influenza pandemic," *Emerging infectious diseases*, vol. 15, no. 6, pp. e1–e1, 2009.

[34] M. T. Osterholm, "Preparing for the next pandemic," *N Engl J Med*, vol. 352, no. 18, pp. 1839–42, 2005.

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