

Landing on Mars: A Cross-Institutional Research-Based Seminar Series

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Engaging students in research can take many forms and such research-based learning is widely perceived as beneficial for student engagement and learning outcomes. Here, we report on our experience with organizing a cross-institutional seminar series dedicated to the question of where on Mars to land a coming NASA Mars mission. The seminar series was connected with the professional process for answering the same question and was organized through teleconferences and an internet site together with local discussions at seven participating institutions. We report on our own reflections as well as student reactions collected through group interviews at five participating institutions. We discuss the results against a model for research-based learning. Coordinating the seminar series across seven institutions and several time zones proved inspiring but challenging. Many specific aspects of how the class was organized could have been improved, but students generally reported high levels of engagement derived from the cutting-edge research nature and current relevance of the subject matter.

The planet Mars is intensely studied because of its relative accessibility and its many points of similarity to Earth (Ehlmann et al., 2016). The process of planning a robotic Mars mission lasts a decade or more from the first programmatic decisions and until launch. Mars contains as much land area as all the continents of Earth combined, but a Mars rover can only traverse up to a few tens of kilometers in its lifetime (Arvidson et al., 2011). Thus, deciding where on Mars to land is a critical early decision that has a major impact on the eventual success of a Mars rover mission. For this reason, Mars scientists invest significant effort in the landing-site selection process. Dozens of potential sites are proposed, data from Mars-orbiting satellites are analyzed in detail, and hypotheses are presented and criticized in a process that lasts several years (e.g., Grant, 2018).

NASA's Mars 2020 *Perseverance* Rover launched on July 30th, 2020 (Farley & Williford, 2017; Farley et al., 2020) and landed on Mars February 18th, 2021. In August 2015, the number of landing sites under consideration for the Mars 2020 mission had been reduced to eight. As members of the mission science team, we decided to organize a teaching effort in the spring semester of 2016 dedicated to analyzing these eight proposed landing sites in the light of the goals and capabilities of the coming Mars mission. At short notice, we organized a cross-institutional seminar series titled, *Mars 2020 Seminar: Scientific Issues in Mars Landing Site Selection*. The seminar series was organized in seven *nodes* at seven participating institutions. The nodes were at California Institute of Technology (Caltech), Purdue University (Purdue), Cornell University (Cornell), Western Washington University (WWU), Arizona State University (ASU), Stony Brook University (SBU), all in the United States, and at University of Copenhagen (UCPH) in Copenhagen, Denmark.

In this paper, we outline the planning and execution of the seminar series, describe student reactions collected through interviews, and summarize our experience from the process. In particular, we explore the student experience of the seminar series as an opportunity to engage in cutting-edge international research. Our ambition was that the specific research question - "Where to land on Mars?" - would drive high student engagement to the mutual benefit of students as well as researchers. We hope our experiences may serve as inspiration and guidance for others attempting similar efforts in diverse academic fields.

One aspect of the seminar series, the recurring remote interaction, is perhaps especially relevant now due to broad global adoption of remote teaching and videoconferencing methods as a result of the COVID-19 pandemic. Our experience with the execution of this seminar series in the spring of 2016 may be of particular interest to educators struggling with the execution of remote teaching during the current global crisis.

Theory

The seminar series was an attempt to involve students in a cutting-edge international research process associated with a high-profile space mission. At the same time, it was an experiment in including students from diverse academic backgrounds and at many academic institutions organized through internet groups and teleconferences in combination with local in-person classroom discussions. In this section we briefly discuss two widely-used theoretical concepts central to this article and how we apply them. The central concepts in this article are student engagement and research-based teaching and learning. There are only few studies in the literature that explicitly address the link between

research-based learning and student engagement, which is the focus of this article.

Student Engagement

Student engagement is a broad term encompassing student motivation, participation, and involvement in academic studies. It may also be described as the opposite of alienation or of apathy, disillusionment, and engagement in other pursuits. Some definitions of student engagement focus on “the extent to which students are engaging in activities that higher education research has shown to be linked with high-quality learning outcomes” (Krause & Coates, 2008, p. 493). Due to the diversity among the local practices and conditions surrounding the seminar series (e.g., the amount of time available for local discussion varied widely from node to node, and students at some nodes received formal academic credit, while others did not) it was not feasible to collect systematic data on comparable learning outcomes. Instead, we assume here that any expression of student engagement could contribute to the overall learning outcome. This assumption is based on an extensive literature (e.g., Trowler, 2010) that demonstrates a generally positive correlation between student engagement as measured by investment of time, effort, and interest in academic activities and outcomes such as increased performance, persistence, and satisfaction. Thus, high student engagement is generally accepted as desirable and central to successful learning. As such, it serves as a useful concept for examining the efficacy of the seminar series in its entirety as well as the individual activities involved.

The work by Fredricks, Blumenfeld, and Paris (2004) differentiates between three dimensions of student engagement: (a) behavioral, (b) emotional, and (c) cognitive. Behaviorally engaged students attend class and participate, displaying a positive attitude. In this context, we study student commitment to the various activities in the seminar series as well as retention throughout the seminar series. Emotionally engaged students experience feelings such as interest, enjoyment, and a sense of belonging, which in this context is particularly linked to the degree to which the students feel that they are an active part of a research endeavor. Cognitively engaged students are committed to their studies and willing to expend time and effort mastering difficult skills or concepts. This dimension of engagement is linked to the opportunities and barriers for learning posed by the cross-disciplinary, trans-institutional, and difference in academic level aspects of the course. The cognitive load on the students involved in such a complex learning environment is expected to affect their engagement in the seminar series. It is possible for individual students to display engagement in only one or two of these dimensions.

It is important to note that student engagement is a highly contested concept and has been used by many different actors ranging from political entities and government bodies to academic researchers resulting in a dilution of the meaning of the concept (Bryson, 2016). A recent development within the field has been to focus the research on educational activities where students are engaged as active partners (Matthews, 2016). Such student partnerships represent a subtle but important shift from attempting to achieve student engagement towards more process-oriented ways of thinking about where and how students can play an active role in education:

The unique value of a partnership approach lies less in the emulation of existing work than in the possibilities it creates for discovering learning and teaching practices, and institutional structures and working arrangements, that have not yet been experienced or even imagined. Partnership between students and staff (and between student peers) involves questioning and sometimes letting go of existing and familiar ways of working and learning, and requires instead trust in a shared process that is inherently unpredictable in its outcomes. (Healey et al., 2014, p. 55).

Student partnerships can emerge in educational settings where there is opportunity for students to play a part in shaping a variety of educational activities. A seminal report maps four broadly overlapping areas of educational activities where student partnerships may arise (Healey et al., 2014, p. 8-9):

- learning, teaching and assessment
- subject-based research and inquiry
- scholarship of teaching and learning
- curriculum design and pedagogic consultancy.

In this context, the area of subject-based research and inquiry is particularly relevant as the seminar series examined here exemplifies an attempt to engage students in research wherein, they could contribute to the research as well as defining the teaching context they participated in to some extent. Even though it remains a challenge for most institutions to achieve genuine student partnerships (Bovill et al., 2016), our expectation for the seminar series was that the students experience *some* degree of partnership with the teacher/researchers and, therefore, exhibit high engagement.

Research-based Teaching and Learning

Linking teaching and learning to research activity is an ambition first formulated in Humboldt’s ideal for the university (Schimank & Winnes, 2000), and the justification and implications of the so-called research-teaching nexus in higher education has been widely discussed (Malcolm, 2014; Prince, Felder & Brent, 2013). Introducing student research into the undergraduate curriculum poses many challenges (Brew,

2013). However, there are now many examples of student involvement in research at the undergraduate level (Healey & Jenkins, 2009a) particularly as a way of engaging students.

There is no consensus as to what is meant by research-based learning, and involving students in research can be achieved in many different ways (Nuchwana, 2012). Some of the potential benefits of linking research and teaching include student retention, preparation for future jobs (Weaver et al., 2008), personal/professional gains (such as confidence in doing research, establishing working relationships), specific skill gains (such as communication, lab techniques) as well as the ability of “thinking and working like a scientist” (Seymour et al., 2004, p. 1). In addition, students are likely to achieve a deeper level of learning and understanding in an active learning environment, when they are involved in research activities (i.e., research-based learning; Healey & Roberts, 2004). A recent review paper showed a positive effect on students’ research skills, interest in the subject, research in general, and critical thinking for students involved in research-based learning in science and engineering (Camacho et al., 2017).

A common model for distinguishing different variations of research-based learning is the model devised by Healey and Jenkins (2009b) and reproduced in Figure 1. The model has two axes: (a) one measuring the degree of active student involvement and (b) one measuring emphasis on content versus emphasis on processes and problems. This leads to a fourfold division into (a) research-based, (b) research-tutored, (c) research-oriented, and (d) research-led activities, that can all be described as research-based learning. The model allows for a nuanced examination of teaching activities and provides a framework to describe the different elements of the seminar series.

In our context, we understand the right-hand side of the chart in Figure 1, denoted “emphasis on research processes and problems,” as working directly with primary data in some form. The primary data available for analysis of landing sites on Mars are data from instruments on Mars-orbiting satellites. Many different datasets exist (images, 3D terrain models, spectra, etc.) and can be accessed via online databases. Often data from many instruments are co-registered and imported into mapping software where they can be overlaid, and second-order analyses may be performed such as compositional and geological mapping, dating via impact crater statistics, and many other techniques. Alternatively, working directly in the field or laboratory with Mars-analogue terrains or samples, would also constitute a form of emphasis on research processes and problems. The left-hand side, denoted “emphasis on research content,” we interpret as working with interpretations, comparisons and big-picture

understanding based on existing analyses of primary data from textbooks or peer-reviewed journal articles.

The top-right quadrant (research-based) then represents independent analysis of primary data in some form, whereas the lower-right quadrant (research-oriented) would be organized training in skills needed to perform such independent analysis (e.g., class training in how to access and process Mars satellite data). The top-left quadrant (research-tutored) represents independent, qualified discussion, criticism, and comparison of data analysis and interpretations in the published literature, while the bottom-left (research-led) is lectures or presentations (e.g., of front-line research results) with students more in the role of audience.

Given these definitions, we may look at how the activities of the seminar series map on to the four quadrants of the Healey and Jenkins (2009b) chart:

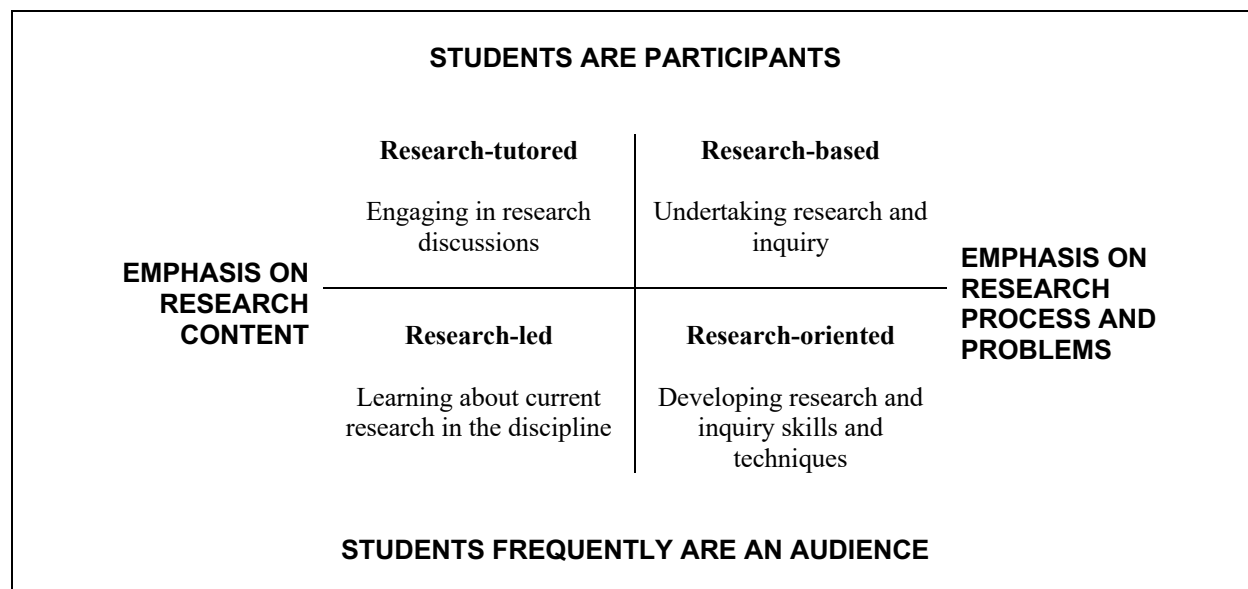
- Research-oriented activities were essentially non-existent. There was no structured training or introduction given to skills and techniques needed to access and work with primary data. Many students had some of these skills, and some students did not; some skill-transfer probably happened between students during the process, but it was not a goal or priority.
- Research-led activities were not dominant but were a significant element. Several weeks were explicitly given to cover various types of background or introductory material. A core element of the class was teleconference presentations in which one group of students would be active presenters, but the rest would be a more passive audience, and thus, perhaps, in that moment also reside in this quadrant.
- Research-based activities were present but again not dominant. The seminar series did not directly engage students in independent analysis of primary data. However, it was not uncommon for students with the required skills to access primary data as part of their preparation to present in class. Also, a significant fraction of participating students undertook such inquiry into prospective landing sites as part of thesis projects either in parallel to or after the seminar series ended. For a significant number of students, the seminar series inspired independent research contributions based on primary data, and conversely independent student research activities enriched the discussions in class.

- Research-tutored activities were the dominant elements in the class. Students and teachers engaged in reading and discussing research. When preparing to present in teleconferences, students would engage with primary literature and student presentations would be followed with open discussion with both students and teachers contributing. During local discussions, students would also be active contributors.

Healey and Jenkins (2009b) argue that all four types of research-based learning are valid and valuable

Figure 1

Healy and Jenkins' 2-axis Model of the Nature of Undergraduate Research and Inquiry (Healy & Jenkins, 2009b)



and that they should be combined to accommodate student heterogeneity. The seminar series encompassed different activities covering at least three of the four quadrants of the Healey and Jenkins chart, but it consisted mainly of research-tutored activities.

Method

This is a qualitative study of students' responses to a series of teaching activities involving varying degrees of research-based learning described below.

Organization of the Seminar Series

The seminar series was loosely organized through a Google group where a subject was pre-defined for each week before the beginning of the series. Subjects ranged from specific studies of the eight prospective landing sites on Mars to explorations of more general scientific subjects of relevance (e.g., Mars mineralogy or organic concentration in terrestrial deltas). Every week, one node was the lead and was responsible for (a) assigning reading material and (b) for leading the discussion at a weekly teleconference. Each node also held local discussions about the assigned subject for the week. Three weeks were dedicated to plenary teleconferences intended as more loose summary discussions. The Google group website included an online forum with a weekly forum thread assigned to student discussions about the subject of that week. During the seminar, two informal meetups were organized during two relevant academic conferences. This gave students who happened

to be present at these conferences a chance to meet participating students from other nodes in person. Finally, a few students (for other reasons) did longer or shorter exchanges between participating nodes during the seminar and thus participated from several different nodes at different times.

Participating Students

A total of 39 students followed the seminar series full-time. Another six students dropped out of the class relatively early or were permitted by arrangement to show up only irregularly. Of the 39 full-time students, 10 were undergraduates, 19 were junior graduate students (before master's degree or similar), and 10 were senior graduate students. The number of students at a given node ranged from two to nine. Each node had a node organizer/teacher who was a professor at the institution, except ASU, where the node organizer was a senior graduate student. The majority of the 39 full-time participating students received some form of formal academic credit, although this took varying forms between nodes. In some nodes, the seminar was listed as a course in the formal course catalogue, while in others, participation was included in an existing class. In some nodes, some students were credited for their participation as an independent project. Some of the students that received formal credit were required to turn in written assignments at some point during the seminar series. None of the organizing professors received any formal teaching credit at their institution, although in many

cases the participation still had career value (was mentioned in the university newspaper or on the university webpage, was mentioned in yearly review, etc.).

Data Collection and Evaluation

We collected student reactions to the seminar series during semi-structured group interviews (Kvale & Brinkmann, 2008) at five of the seven nodes (ASU, Cornell, Purdue, UCHP, and WWU). In total, 25 students participated in these interviews. The interviews were conducted in person by the teacher at the node during the last few weeks of the seminar. The interview guides provided to the teachers are available in Appendix A. The interviews lasted about one hour and were divided in two parts.

In the first part, students were asked to rank a number of course elements according to how valuable the student found them for their learning: individual reading, online forum, teleconferences (own group as lead), teleconferences (other group as lead), teleconferences (plenary), local in-person discussion, and assigned essay. This was then followed by an open discussion between students of their rankings and the arguments for these.

In the second part, students were asked to individually draw by hand curves of their level of motivation as the seminar went on. This was again followed by a discussion focused on what times and factors had students feel motivated and engaged, and what factors might have had a demotivating effect.

Finally, the interview concluded with four predefined questions on other motivating or demotivating factors during the seminar series. The interview recordings were imported into the Atlas.ti program, and we performed a thematic analysis (Braun & Clarke, 2006) with focus on responses relevant to the subject of research-based learning. A number of other interesting themes emerged as well, and we describe results of this thematic analysis below.

In addition to the group interviews, we also set up a dedicated thread on the Google group forum for students to respond in writing. This thread collected four detailed student responses, and these were included in the thematic analysis as a supplement to the recorded group interviews.

Results

Rankings and Motivation Curves

At the beginning of the group interviews, students were asked to rank seven different elements according to “which of the elements you feel have been most valuable

for your learning process.” A few trends emerged from this exercise. Most clearly, the Google group forum discussions were ranked last by 20 out of 25 students. Local group discussions were generally ranked relatively high, particularly at nodes that had significant time available for local discussions. Teleconferences were experienced as more valuable when the local group was presenting. The rankings are discussed in more detail in Appendix B.

At the group interviews, students were also asked to individually hand-sketch curves of their changing motivation during the seminar series. These curves differed substantially between students. Nonetheless, some general trends can be pointed out: More students indicated an overall drop in motivation than the reverse. In many cases, this drop was more pronounced towards the end of the seminar. About half of students indicated by text that outside factors (breaks, exams) were drivers of low motivation. Finally, about half of students reported motivational highs when presenting and preparing to present at teleconferences. All motivation curves are presented together with some more detailed discussion in appendix B.

Thematic Analysis of Interview Data

Here, we present a thematic analysis of the group interviews and forum responses structured according to emerging themes. In the discussion section below, we will discuss these observations in the context of student engagement, of research-based learning, and of the Healey and Jenkins (2009b) chart reproduced in Figure 1.

Diversity of Student Background

The group of participating students in the seminar was diverse in terms of academic level. Students also had varied disciplinary backgrounds including aerospace engineering, chemistry, physics, planetary science, geology, and astrobiology. The seminar was organized at short notice prompted by our engagement in the Mars 2020 landing site selection process, thus recruitment was very much by word of mouth or perhaps more precisely: recruitment at each institution was largely among students that already had a personal connection to the node organizer or teacher at that institution as members of a research group or similar, and there was no attempt to define or police a requirement for a certain academic level among participants. The variety of academic levels came about as a result of the opportunistic and short-notice nature of the organization of the seminar.

This diversity of student backgrounds and levels could be viewed in many ways as a strength, as it reflected the multitude of backgrounds within the science and engineering teams that run a Mars rover

mission. However, it also caused frustration among some students.

Many students experienced a lack of background knowledge as limiting for their motivation or learning, as expressed by a Cornell student: "If you weren't familiar with this stuff when they are throwing all of these different phyllosilicates at you and all these different kinds of features it is like: Wow, why do I care?" A student at ASU put it this way: "There are certain words or certain things that are mentioned all the time and if you don't know what they mean when you don't have that knowledge then you quickly forget it." Many students expressed a wish for more introductory lectures early on to familiarize the class with the necessary background knowledge.

On the other hand, a few of the older students experienced the opposite problem. One ASU student said, "My motivation started high when we kind of didn't know what the scope of the class was when I found out I might have been pretty qualified then, my motivation dropped." This was a general problem at the ASU node, which saw several students leave the class early in the semester: "... they were disappointed with the level, the requirements of the class and the small amount of output that they would produce and what they would get out of the class." A critical Cornell student summarizes both sides of the problem this way:

It's hard to know who this class is for...It kind of felt like if you know about Mars there [*sic*] you were just repeating the stuff that you already knew in the discussion and nothing really new was learned and if you didn't know about Mars you didn't really learn anything because all the stuff that was being talked about was talked about at a high level.

The diversity of disciplinary backgrounds also had a positive side. When grappling with the interdisciplinary problems of the class, it was helpful to be able to draw on students with different backgrounds. A student said about local discussions in the UCPH group, "We were able to discuss amongst ourselves because there were some geologists there and some physicists - with different backgrounds so that actually worked really well." Sometimes this kind of cross-disciplinary transfer of knowledge was less about explicit facts and more concerned with implicit knowledge or familiarity with certain types of datasets. An ASU student noted,

People who are dealing with orbital datasets, I think it was probably a little difficult for them to grasp all of these microscale...features that are required to make a decision about a potential biosignature, and vice versa I only deal with microscopic datasets and

it is hard for me to visualize kilometer-wide... images.

Teleconferences

The lack of background knowledge was experienced most acutely when interacting with other nodes in the wider group through teleconferences or the Google group forum. In four out of the five group interviews, students reported feeling intimidated by the wider group and feeling like students from the other nodes were much more competent. A student at WWU described the experience this way: "When we come online, some mysterious voices, they all sound like science wizards - beyond me - so it is much harder to voice curious thoughts."

On the other hand, many students reported that they worked harder and were more motivated when they had to present to the wider group. A Cornell student shared, "Having an audience that really expects a level of knowledge and being able to answer questions from you really motivates you to get involved and learn about a lot of specifics." Generally, students experienced that they learned a lot from presenting at teleconferences because of the motivation and level of work required: "It kind of forces you to dig in deeper and get a deeper understanding of the things you are going to talk about at the telecon," a student at ASU said. Just being immersed in the wider group was experienced as interesting and motivating by some students. There is "something really awesome about the fact that we are talking to someone in Denmark about Mars, that is just a cool thing" as a student at WWU said. Also, the wider group brought students into contact with a lot of expertise that was not always locally available. An ASU student said, "There are only eight sites left and we have some of the best experts in the world here who have proposed this, but they are also trying to be objective about it. That is a pretty good feeling."

The intimidation experienced at teleconferences was related to the anonymous nature of the format. Many students suggested that some video component to the teleconferences or an online presentation page might have helped alleviate this feeling. A WWU student said,

If there was a way that we could see whoever was presenting that day just so we could put a face to the name or the voice, I think that would help humanize the voices behind the curtain as it were.

The students that got to meet in-person with students from other institutions generally found the wider group to be less intimidating and more motivating than did other students. This was brought out at the Purdue discussion when students were asked, "Did the chance to

interact with other institutions motivate you?" Going around the room responses were "No", "No", "Not really", "No" and then: "Yes." As it turned out the sole yes vote was from the one student in the room who had been at an in-person meet-up at a conference. This student then elaborated:

It is like these are the future colleagues who are gonna [*sic*] be working with us on these missions and stuff in the future and so being able to go: yea, we took this class together even though we didn't go to school together it is pretty awesome.... Just to be able to be in the same class as someone from all these different places all working towards the same goal.

A Cornell student recorded a similar experience: "Once I got to know them at a more personal level it just made it a lot easier to feel part of the discussion to feel part of the group."

Local Discussions

The intimidation and lack of personal connection experienced by many students when interacting with the wider group made the local group discussions extremely important. The local group was experienced as a more intimate, safer environment. It was "easier to talk and put your opinion in because you knew everyone else in the room" (WWU student). The local group was a place to ask questions: "basically we just asked [the teacher] a lot of questions, and he explained it so in that way we actually got a really good overview of the different aspects of the topic of that day" (UCPH). In the local group, students could have "real open ends of thought come out in the discussion" (Purdue) and thus test ideas before raising them with the wider group. Generally, students were highly engaged in local discussions and local discussions were experienced as a very valuable element of the class. At Cornell, where less time was available for local discussion, this element was experienced as less valuable.

Often back-and-forth discussions within the local group was happening real-time during teleconferences. An ASU student described,

People may be more hesitant or nervous to bring something up, but then they mute their telecon and then talk about it on the side and get, like, a group consensus, a group opinion on that topic, and then share it with the larger multi-institution group.

This dynamic was very effective and could function almost like built-in, on-the-fly buzzing sessions. The UCPH group had an interesting and quite successful

variation on this: Due to the time difference, the Copenhagen group usually did not participate real-time in the teleconferences (except when presenting). Rather the Copenhagen group would listen to recordings of the week's teleconference during their local discussion. While this removed the chance for direct interaction, it did provide, instead, the option for pausing the teleconference recording any time a student had a question or a comment. This was used a lot and appreciated by the students. "If you didn't really understand something you didn't have to wait until the end and maybe forget it." Another Copenhagen student added, "Maybe everybody should do it and just call in for the discussion." There are many potential variations on the set-up.

Even though many students experienced the local discussions as the single most valuable element of the class, and often the setting where learning happened, the existence of the wider group was still a crucial element. A UCPH student explained it this way: "For me, saying that the local discussions were important, that was because it was based on other people's views and how they interpreted it." Local discussions were prompted by input from the wider group and the existence of the wider group was a crucial element in student motivation and in seeding the local discussion.

The Google Group Forum

The students generally did not see the Google group forum as a very valuable element of the course. As teachers, we tried to push students to engage in the forum threads, but it was very clear from the written evaluation and the group interviews that most students viewed the forum quite negatively. Opinions ranged from "not as helpful as the other elements" (WWU student) to "completely not useful" (Purdue student). The forum was even more intimidating than the teleconferences because of the potentially larger audience and the permanent nature of a written comment. A WWU student said, "The intimidation factor is worse with the Google group where if you're wrong then you're wrong permanently," and a Purdue student put it thus: "I liked the local discussion because I didn't feel as much like an idiot and I didn't like the Google group because I felt like an idiot."

The students experienced the forum as more of a collection of comments than a dialogue. An UCPH student wrote in the evaluation thread, "I felt like many people were forced to write something and comments weren't connected to each other sometimes, hence a collection of monologues - not a discussion. This doesn't feel very engaging." A Cornell student made a similar comment in the interview: "It felt very forced and more, eh, there were a lot more questions being asked than there was discussions or answers." Several students

suggested that these problems were at least partly related to the setup of the forum as a single thread per week and that perhaps a better forum setup would have resulted in more engagement. A few older students put a slightly more positive spin on the criticism and pointed out that the work involved in writing a -thought-out forum post had value. For instance, a Caltech student wrote in the evaluation thread, "While I agree with the general idea that the online 'discussions' could be improved, they did a good job forcing me to crystallize my own thoughts about the readings, so I think they were still worthwhile." This was a clear minority view, though.

The Research Experience

While the teleconference format was experienced by many students as to some extent frustrating and intimidating, it did represent an experience of a very common framework used in the real world of planning and conducting scientific space missions. Thus, becoming familiar and comfortable with this format is training in an important real-world skill. This was not lost on the students:

The telecon system represents real life, right, I mean this is how telecons are going to be for our careers... this is how, you know, NASA telecons work. You have multi-institutional teams all getting together at the same time and space to hash out - stuff - make decisions. So, I think this is a good representation of what to expect in our careers and I think that is a good experience to have. (ASU student)

In the forum evaluation thread, a Caltech student expressed a similar sentiment: "There ... are definitely skills involved in presenting/discussing on a speakerphone and I feel that doing some of that in supportive class format was a minor benefit of the course."

More broadly, very many students expressed appreciation for the chance to participate in some small way in the landing-site selection process as it was happening: "Because these landing sites are actively, at the present time, being considered and people are fighting over their favorite landing sites...Having that kind of happening in real time definitely improved the motivation" (ASU student). A student at WWU expressed a similar sentiment: "It is a big thing to be a part of. Somebody asks, what did you do this afternoon? You know, discussing where a three-billion-dollar space robot is going to go...it's pretty exciting! It's definitely a motivating factor." The seminar did not only happen in parallel to the official selection process. Rather, all of the teachers were in some way involved in the official process as well - some with fairly high profiles - and the seminar was part of their learning and decision-making.

Thus, the students were in a very real sense contributing, which was a strong motivator. A WWU student said, it was "definitely a motivation to analyze every single aspect because there are some higher stakes to it if you are skimming something and you miss something it could actually have an impact." Another WWU student agreed:

The stuff that we are doing in this group is super-exciting because it is on the bleeding edge of knowledge, basically...we are right there with all the bigwigs and they are making their decision and hopefully we can put our 2 cents in - help out a little bit.

This sentiment was widely shared and appeared in some form in all group interviews. A Purdue student half-teasingly put it this way:

I like to think that what we think in here and some of the conclusions we make influence professor X [sic] at Purdue and professor X's opinion is very well heard throughout the Mars community and so therefore our opinion leads to that. Go professor X! (Professor X refers to the local node teacher)

Conflict with Other Classes

The short-notice organization of the seminar plus the need to coordinate calendars between seven different institutions caused a significant amount of friction. For instance, the UCPH group did not very often participate live in teleconferences. This was because the time that worked best for the other institutions was an afternoon, which was relatively late evening in Copenhagen. Some institutions had a quarter-based calendar while others had semesters, thus the seminar series would run through times when some institutions had breaks or exams, preventing some students from participating fully. The experienced fall-off in motivation late in the class (see rankings and motivation curves section) is to some extent related to this. Some institutions recessed for summer break before others, and so class participation tapered off slightly at the end. More seriously, perhaps, not all institutions were able to have the seminar accredited as a formal class, and students had to get credit through other means such as an independent project or similar - or simply follow the class without formal credit. At times of high workload, the seminar would lose out to other classes that were worth more credit: "When workload gets high, I have to triage my work", as one WWU student said. This was experienced as frustrating when students were motivated and experienced a chance to participate in research but had to prioritize other tasks that were rated as more important by the university: "My ideal scenario for this class is that I am not taking any

other classes ... just do this class the whole time." Many students agreed that more time could have been productively invested in the class.

Discussion

Research-based Learning

We believe that the seminar series was dominated by the research-tutored activities quadrant in the Healey and Jenkins' (2009a, 2009b) model. As demonstrated through the interviews, most students experienced their own participation as contributing to a research process, and this experience was a large motivating factor. Also, the type of activities undertaken in the seminar series closely followed the professional researchers involved in the landing-site selection process. This coincides with Barnett's (2000) definition of research-based teaching where "lecturers adopt teaching approaches that are likely to foster student experiences that mirror the lecturers' experiences as researchers" (p. 163). As teachers, the readings and discussions during the seminar series were actually part of our work on evaluating these sites. Indeed, it was only because the seminar series was a part of our research work that we could justify investing the time, despite not being formally accredited for teaching the class at our institutions.

Student Engagement

Student engagement was generally high, but the results also showed notable differences in how the students engaged in different parts of the seminar series. Fredricks and colleagues (2004) posed that student engagement can be differentiated into emotional, cognitive, and behavioral engagement, which can help explain some of our results.

We saw that student motivation tended to wane over time indicating a drop in emotional engagement. This was surprising given that students were very explicit and positive about being part of authentic research. Although the seminar series was mostly research tutored in nature and thus based mainly on examining existing research rather than generating new knowledge, students generally indicated that they were highly motivated by the opportunity to work on cutting edge problems. For some students, the seminar series also provided experiences relevant for their future work. The fall-off in emotional engagement, therefore, seems to stem from other aspects of the seminar series.

One explanation for the fall-off in student motivation over time could be the differences in students' academic backgrounds which lead to some students feeling that some of the discussions were either irrelevant or too advanced for them. Other students found the series too repetitive in relation to their other

courses and lacked cognitive engagement as they struggled to find relevant challenges for them in the seminar series. The diversity of students' backgrounds, academic level, and overall ambitions posed a challenge to students' sense of belonging (emotional engagement) throughout the seminar series.

In particular, the Google group forum and teleconferences were found to be quite intimidating by many students as they didn't know the other participants. This led some students to doubt their abilities, which affected their emotional engagement negatively. On the other hand, the pressure of performing well in the teleconferences led students to increase their cognitive engagement when preparing presentations, but in the Google group most students were simply too intimidated to take active part. Teachers managed to address student differences to some extent through local activities, and the differences in student backgrounds was highlighted as a source for cognitive engagement in local activities, which were more intimate and conducive for cross-disciplinary discussions requiring different skill sets and knowledge.

Given the ad-hoc nature of the seminar series, we did not manage to arrange and coordinate teaching and learning activities that could have minimized some of these issues. Providing short video or web-based introductions on specific topics or arranging for students to work in groups across institutions based on common backgrounds might have been helpful to increase emotional engagement. Another improvement could have been formulating explicit learning outcomes for students at various levels and in different fields. Knowing what was expected of the students and what the students should be focused on throughout the seminar series could have improved students' cognitive engagement. One important lesson of the seminar series is that investing more time in structuring and planning the seminar with thought given to how to pedagogically address challenges of the format would surely have improved the eventual outcome.

In the end, most students who got involved in the seminar series completed the series. As such, there was a high degree of behavioral student engagement. We do not have substantial data on the few students who dropped out, but there were indications that organizational challenges played a significant part. Both students and teachers complained about how difficult it was to get credit for spending time on the seminar series, which made it difficult to justify spending more time than necessary.

Organizational Challenges

There is no doubt that most students were excited and motivated by the chance to participate in a high-profile research project happening *right now* and this

was reflected in their work effort. These results resonate with the continually mounting evidence that research-based learning can promote student engagement in higher education (Healey & Jenkins, 2009a). However, a significant amount of friction was experienced due to conflicting schedules and problems with getting both students and teachers proper credit for participating. This caused frustration and was a limitation on the amount of time that could be invested by students, and thus ultimately was a barrier to the ideal execution of the idea and to student learning.

Organizing research-based learning activities like the ones attempted here, often relies on being able to grasp a chance at the moment it appears, which can conflict with universities' need for structured and formalized courses and curricula to meet educational standards and ease administration (Macfarlane, 2015). Recruiting students for such initiatives and giving them the freedom to invest the required work effort depends on institutional flexibility from the university system (e.g., allowing new entries in course catalogues with short warning, awarding academic credit to atypical activities, etc.). To some extent, problems coordinating with official academic schedules within and between institutions prevented students from investing the time they would have liked and caused frustration. Overall, however, we found the seminar series to be a successful experiment with cross-institutional research-based learning, although many specifics of how the class was organized could be improved.

Conclusion

Most students experienced the seminar series as a highly appreciated chance to engage in a research project for a high-profile Mars mission alongside the professional researchers. Students reported strong engagement and motivation from the link to the concurrent and ongoing landing-site selection process, even though the majority of the work was based on existing research and not on students' own research projects. The student group was diverse in academic level and disciplinary background, which caused significant frustration from some students and impacted their engagement. Similarly, organizational challenges posed a hindrance for student behavioral engagement.

The remote teleconferencing format was experienced as intimidating by many students, as the participants from other institutions were largely unknown beforehand. Students that had the chance to meet in-person with participants from other nodes generally experienced teleconferences as less intimidating. Also, students reported that in-person discussion in the local group, a much less intimidating environment, was crucial for their engagement, and

learning. As a lesson for educators organizing remote teaching in the time of the COVID-19 pandemic, we found that fostering personal connections between participants was crucial for reducing feelings of intimidation caused by the online teleconferencing format.

Also reminiscent of the recent emergency shift to remote teaching during COVID-19, the seminar series was organized very quickly, in our case to respond to a sudden opportunity. The ad-hoc nature of the organization meant that structure and rigorous pedagogy suffered. Better planning could no doubt have reduced the frustrations experienced by some students in the course.

In summary, this example of research-based teaching and learning was very conducive to students' engagement because of participation alongside professional researchers sharing in their own investigation. Positive effects on student engagement were counteracted somewhat by planning and coordination issues. Research opportunities such as the one presented by the *Perseverance* Mars mission may be difficult to combine with adequate time or resources for proper educational considerations. It, therefore, remains a challenge to link research and education, but such opportunities can be important for student engagement.

Acknowledgements

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Appendix A: Interview Guide and Handouts

Instruction for group interviews

For the interviewer:

Purpose:

The purpose of the group interviews is to collect data from the students regarding their *motivation* and *learning experience*. In order to assure some degree of uniformity in the data, this interview guide has been designed to be rather structured. Please follow the describe procedure as closely as possible to ensure that the data becomes comparable and easy to analyse.

Structure:

The interview consists of two parts, each with individual reflection followed by a group discussion. If there is time, there are a number of extra questions for group discussion. The estimated time frame for the interview is 1 hour. The individual reflection is designed to stimulate specific recall of the various parts of the course in order to qualify the following discussion. It is important that the students get sufficient time to complete the individual reflections before moving on to the discussion.

Practical Information:

Please make sure you have some way to record the session. If possible, please use a dedicated recording device (such as a voice recorder). Smartphones can be sufficient, but the quality of sound varies greatly. If you are more than five people it may be necessary to use more than one recording device to capture the conversation. Please check the equipment prior to the session to ensure that it is working and that you can make out the individual voices of a group.

After the interview, please send the audio recordings and scannings of the two sets of handouts to Kjartan electronically.

Interview procedure:**Introduction to the session:**

Please ensure students that they will not be quoted by name and that they will only be identified as “student X at [Named University]”. Also, explain that you are recording the session and that recording will only be shared with the Copenhagen group.

1. Individual reflection (give each of the students a copy of handout 1):

- Ask the students to individually rank the elements of the course listed on handout 1 according to which of elements they feel has been the most valuable for their learning process (1 is highest).
- Allow the students 2-3 minutes to complete the individual reflection before moving to the next step

1. Group discussion (the interviewer presents the students with the following questions):

- Please share your rankings with the group and discuss why you have ranked them as you did?
- Do you feel that you understand the wider aspects of Mars science/Mars evolution after taking the course or have you mainly learned about specific landing sites?

2. Individual reflection (give each of the students a copy of handout 2, show example):

- Please ask the students to individually draw a curve depicting their changing motivation during the course. For each peak and valley, ask the students to note on the handout what situation triggered the change in motivation.
- Give the students 3-6 minutes to complete the task before moving to the next step.

2. Group discussion (the interviewer presents the students with the following questions):

- What was the most motivating factor in the course and why?
- What was the most de-motivating factor and why?
- Did the fact that these landing sites are under consideration for a real Mars mission matter for your motivation during the course?
- Did the chance to interact with students from other institutions motivate you? How and why?

3. Group discussion (providing that there is time for it, the following add on questions can be posed):

- Where there any particular difficulties with the technical aspects of the course (telecons, google group etc.)?
- What do you think could/should have been done differently?

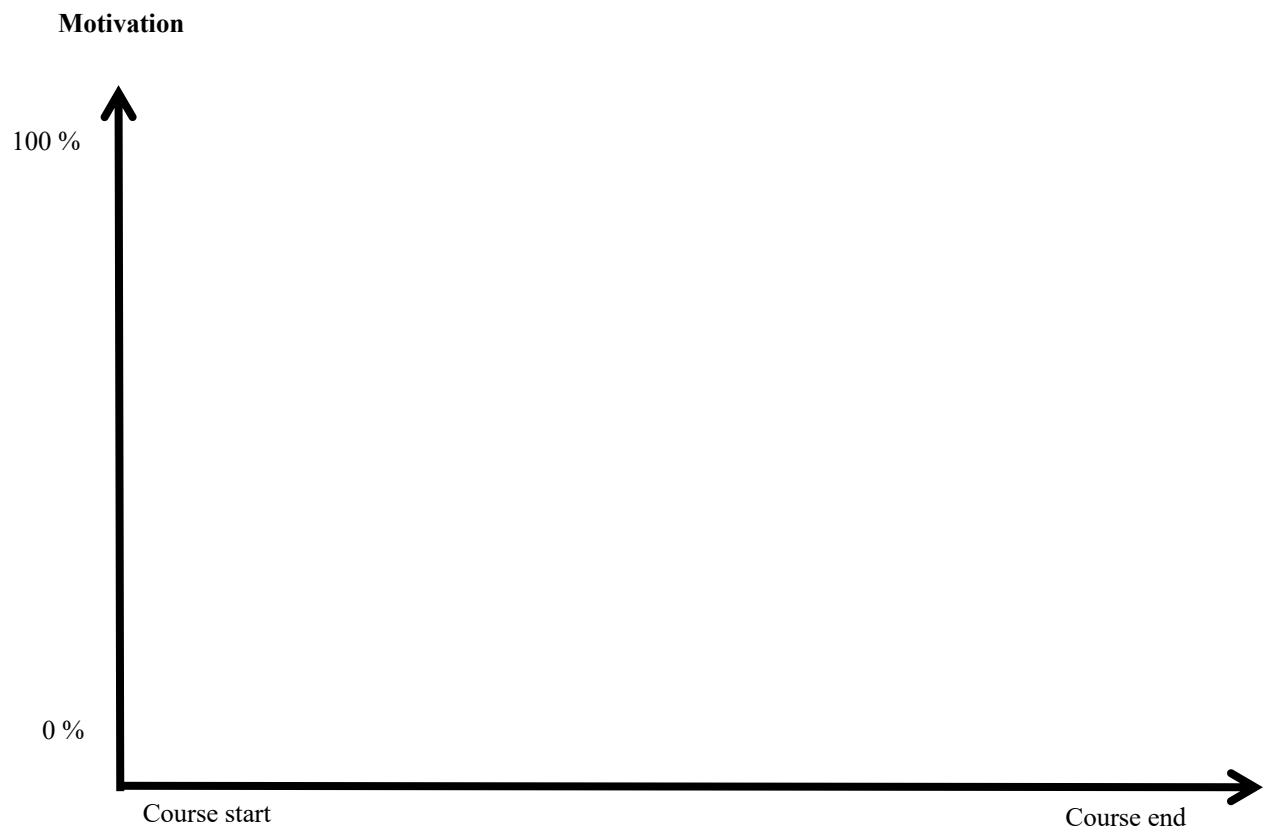
Handout 1

Please rank the following course elements according which of the elements you feel has been most valuable for your learning process. Mark each element with a number starting with 1 for the element that you found to be most valuable for your learning.

Course element	Your ranking
Individual Reading (i.e. the reading list)	
Google group forum discussions	
Participation in telecons with others presenting	
Preparing and presenting at telecons	
“Plenary session” telecons	
Group discussions at local institution	
Assigned essay (only relevant for some students/institutions)	

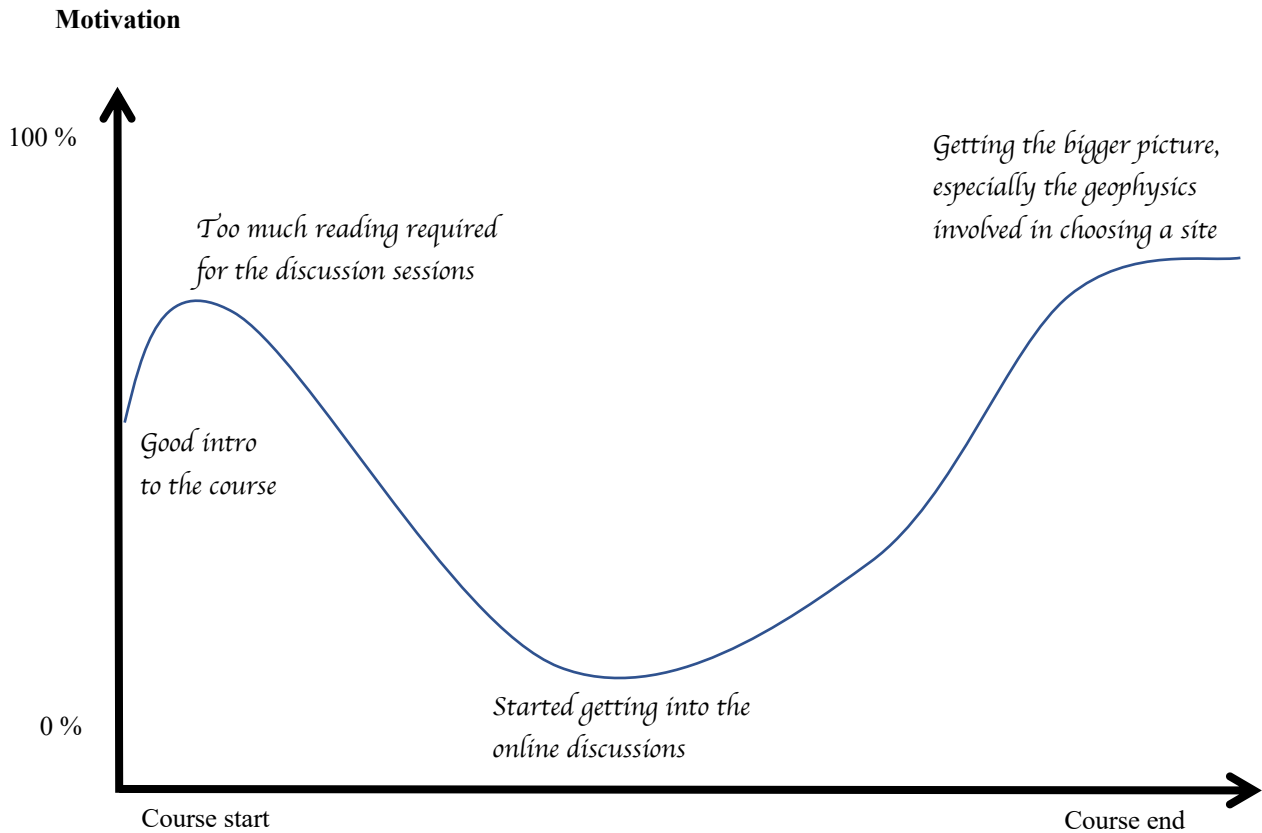
Handout 2

Please draw a rough curve of your motivation throughout the course in the coordinate system below. For each peak and valley you have on your curve, please make a small note to indicate what caused the change in motivation at that time.



Handout 2 - Example

Please draw a rough curve of your motivation throughout the course in the coordinate system below. For each peak and valley you have on your curve, please make a small note to indicate what caused the change in motivation at that time.



Appendix B: Interview Data

Here we provide some more detailed discussion of the rankings and motivation curves from the group interviews.

Rankings

We conducted semi-structured group interviews at five of the seven nodes. Interviews were conducted at ASU, Copenhagen, Cornell, Purdue, and WWU. In total, 25 students participated in these interviews. At the beginning of the interview, students were asked to rank seven different elements according to “which of the elements you feel have been most valuable for your learning process” (see Handout 1 in Appendix 1). For this purpose, we divided the seminar series into the following seven elements: Individual reading, online forum, teleconferences (own group as lead), teleconferences (other group as lead), teleconferences (plenary), local in-person discussion, and assigned essay.

Averages and standard deviations for these rankings are shown in Figure B1. A few conclusions can be drawn from this figure. Most obviously the Google group forum discussions were almost unanimously ranked last. Twenty out of 25 students ranked the forum last. Clearly, the forum discussions were experienced as less valuable than other elements. The rankings for other course elements fall closer to the expected average value of 3.5, scattering between a high of 2.3 +/- 1.5 for the local group discussions and a low of 4.0 +/- 1.2 for plenary telecons. Telecons were experienced as more valuable when the local group was presenting. As discussed in the main text, presenting during a telecon required significantly higher student preparation and effort than merely participating.

Figure B1 does hide some significant node-to-node differences. For instance, students at Copenhagen, Purdue, and WWU collectively ranked local discussions at an average of 1.4 rather than the 2.3 average when the other two nodes are included. Eleven out of 15 students at these three nodes ranked local discussions first. This is related to the amount of time available for local discussion at the different nodes. At nodes that had significant time available for local discussion, this element was experienced as very valuable by the students.

Motivation Curves

During the focus group interviews students were also asked to hand-sketch curves of their changing motivation during the seminar series (see Appendix 1 and Handout 2). The curves are all provided at the bottom of this appendix. These are obviously quite qualitative and individual in nature. Nonetheless, some general trends can be pointed out, both from the shapes of the curves and from the accompanying text comments. Here we point out a few of the more apparent trends.

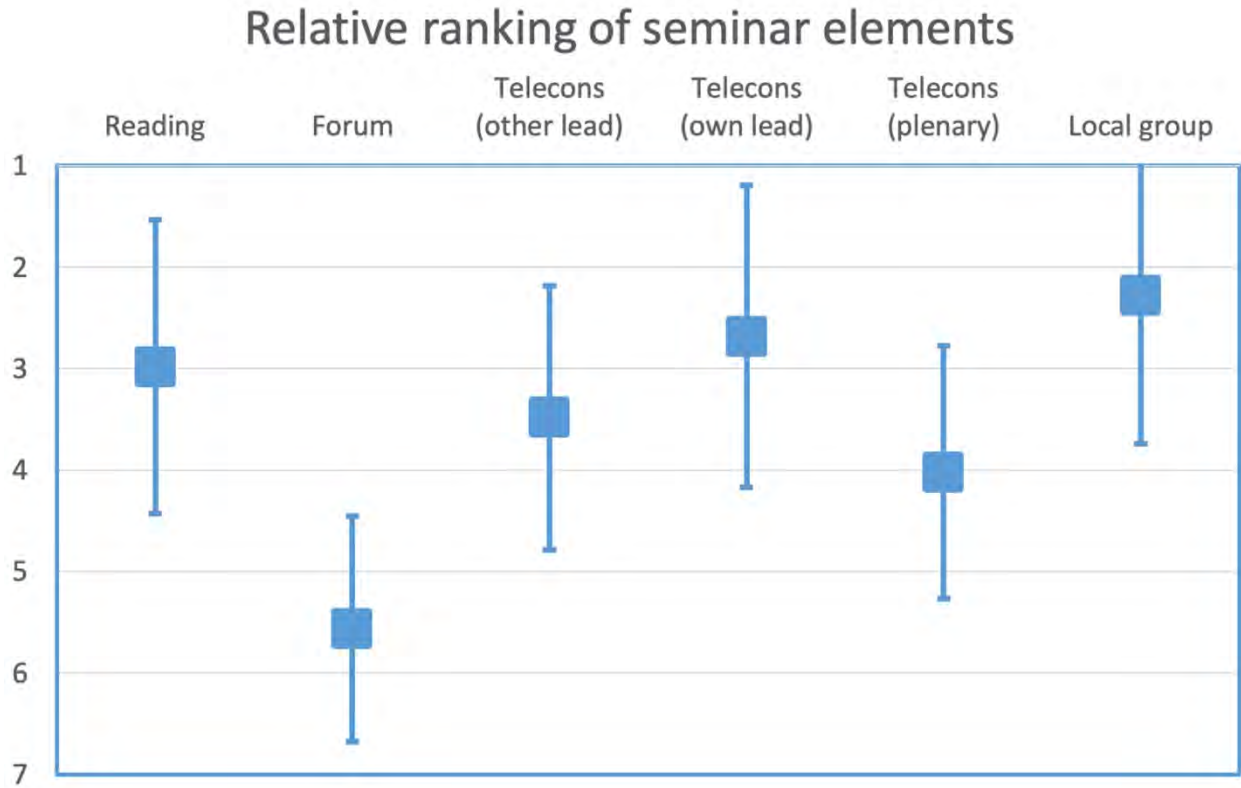
First, 10 out of the 24 curves end clearly lower than they began, indicating a drop in motivation through the seminar. Only four curves end clearly higher than they began. The rest end at roughly the level they began. In many cases, this is dominated by, or at least accompanied by, a dropping trend in the final period. Eleven curves end on a downslope, and five curves end on an upslope. In contrast, similar numbers begin with a downslope as with an upslope (seven each).

More than half the curves (13) indicate by text that periods of low motivation are coincident with various outside factors (breaks, times of high workload in other classes, moving apartment). Three curves indicate by text an association between low motivation and subject covered. Fourteen out of 24 curves indicate high motivation at times when the students' own institution was presenting at teleconferences. Five curves indicate high motivation in association with subject matter.

In summary, more students appear to have experienced an overall drop in motivation than the reverse. In many cases this drop was more pronounced towards the end of the seminar. About half of students indicate outside factors as drivers of low motivation. The seminar series was generally worth less academic credit than other classes, and so at times of high workload, investment in the seminar suffered as students prioritized their time. Finally, about half of students report motivational highs when presenting and preparing to present at teleconferences.

Figure B1

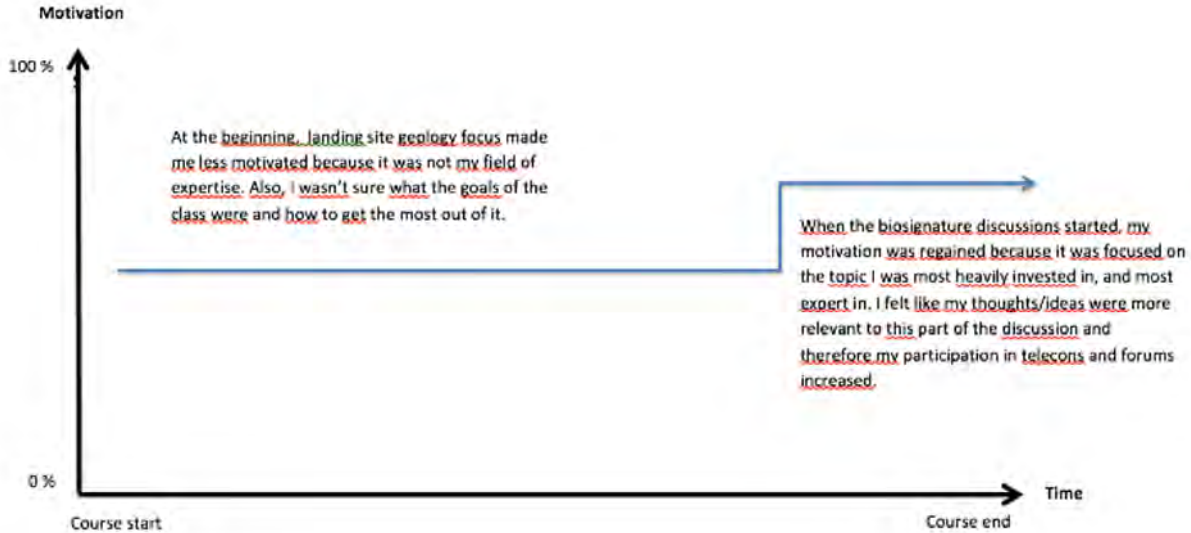
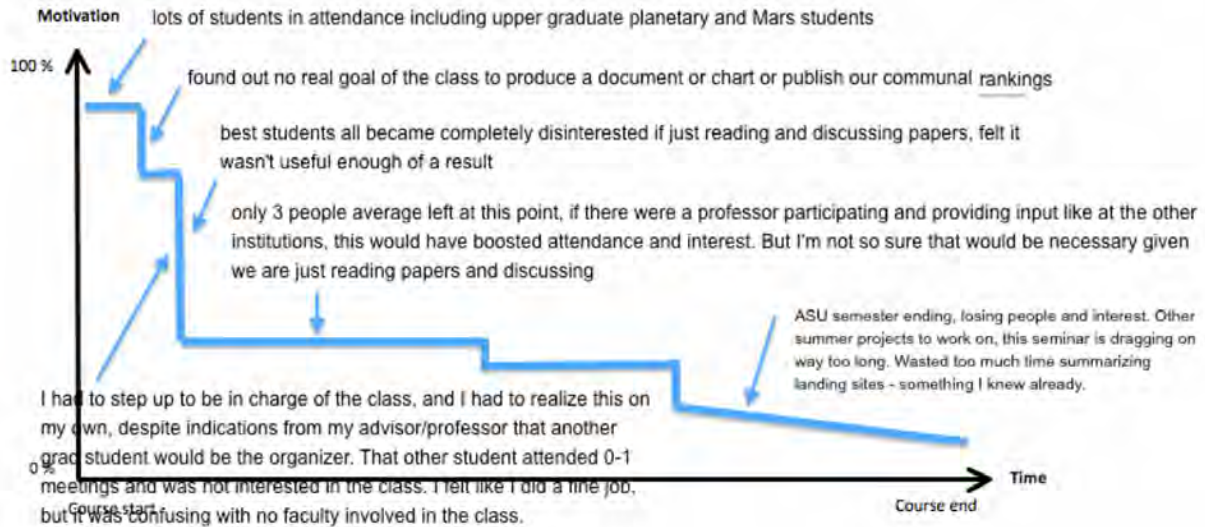
Ranking of various seminar elements according to Handout 1 (see Appendix A). For this figure ranking for assigned essays have been excluded since only 7 interviewed students had assigned essays. For students that included essays in their ranking, values have been adjusted to range from 1-6 (i.e., if a student had essay ranked as 1 and other elements ranging from 2-7, they will appear as ranging from 1-6 in this figure).



Motivation Curves

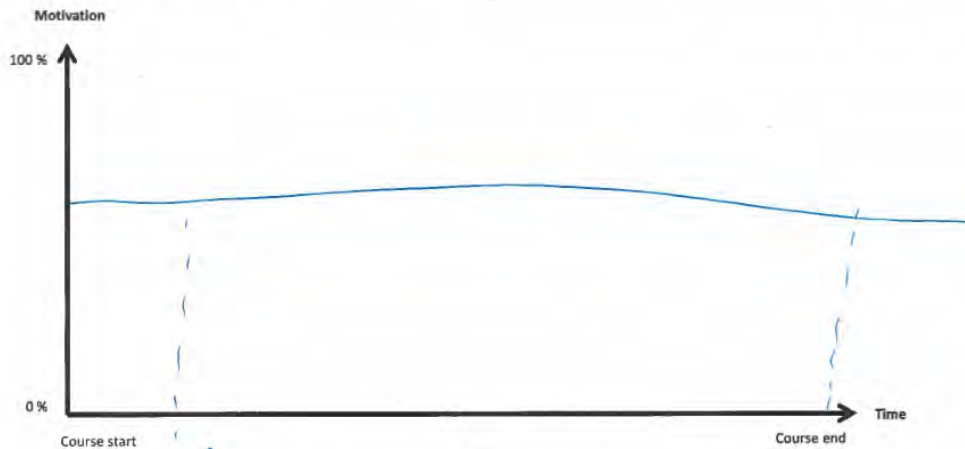
Handout 2

Please draw a rough curve of your motivation throughout the course in the coordinate system below. For each peak and valley you have on your curve, please make a small note to indicate what caused the change in motivation at that time.



Handout 2 A

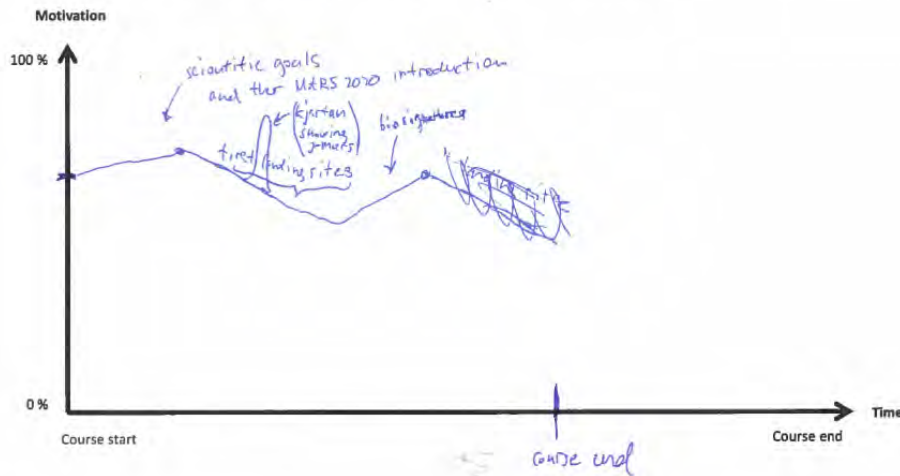
Please draw a rough curve of your motivation throughout the course in the coordinate system below. For each peak and valley you have on your curve, please make a small note to indicate what caused the change in motivation at that time.



maybe these were some fluctuations but in the end it averaged out.

Handout 2 B

Please draw a rough curve of your motivation throughout the course in the coordinate system below. For each peak and valley you have on your curve, please make a small note to indicate what caused the change in motivation at that time.



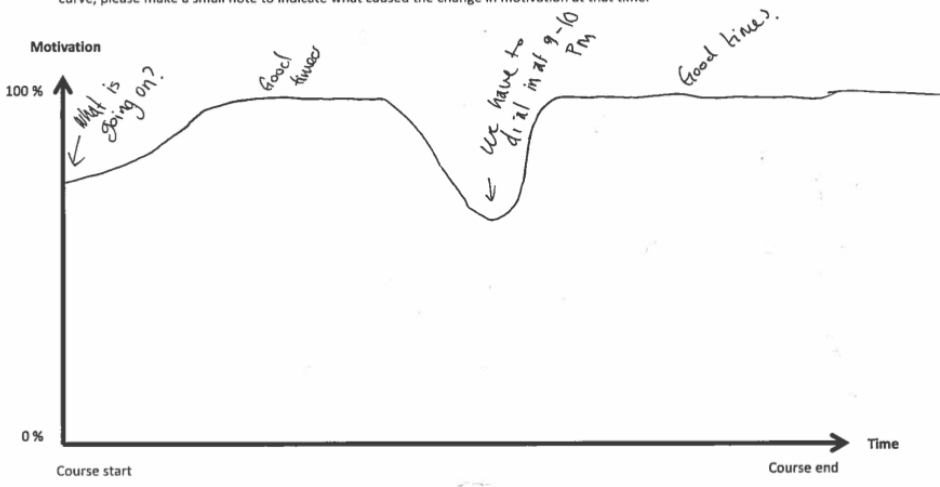
Handout 2

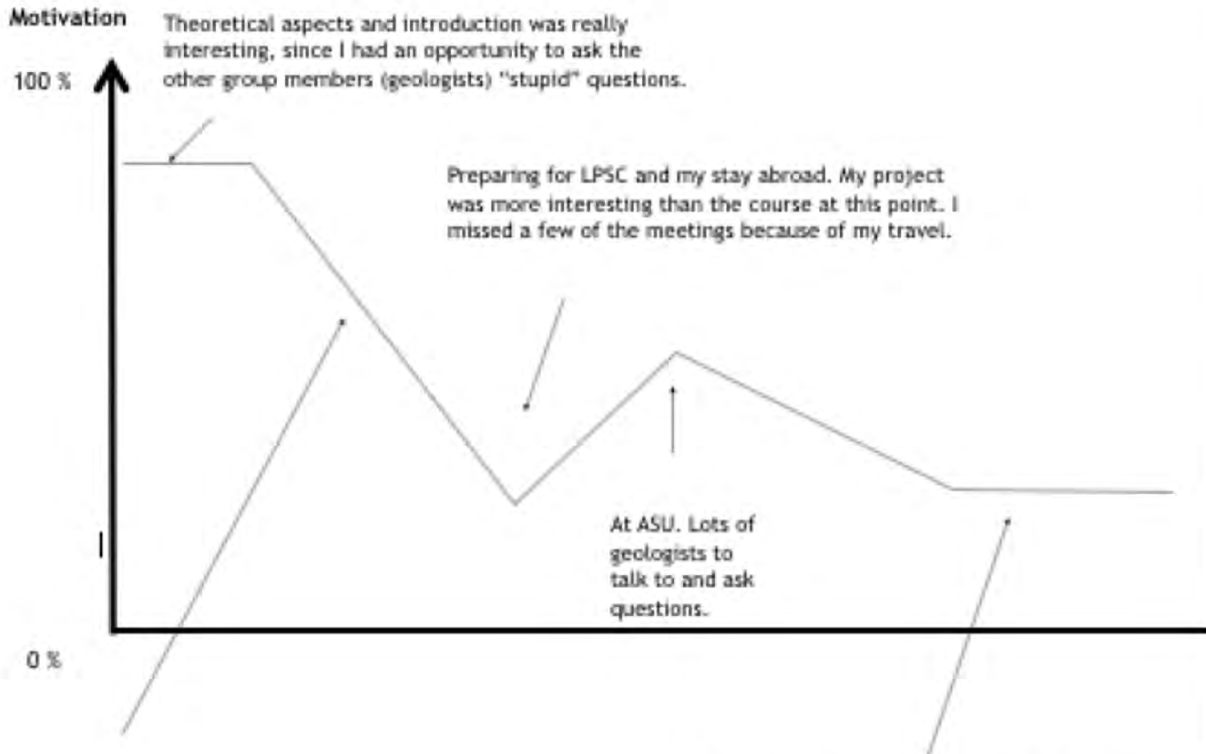
Please draw a rough curve of your motivation throughout the course in the coordinate system below. For each peak and valley you have on your curve, please make a small note to indicate what caused the change in motivation at that time.



Handout 2

Please draw a rough curve of your motivation throughout the course in the coordinate system below. For each peak and valley you have on your curve, please make a small note to indicate what caused the change in motivation at that time.



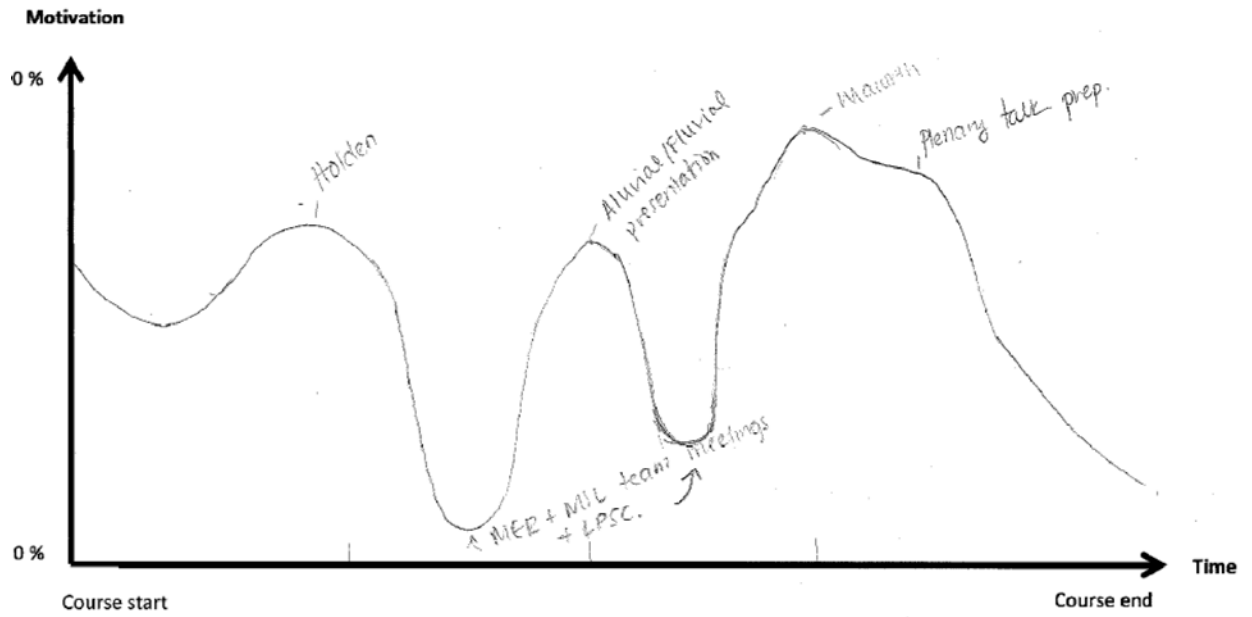
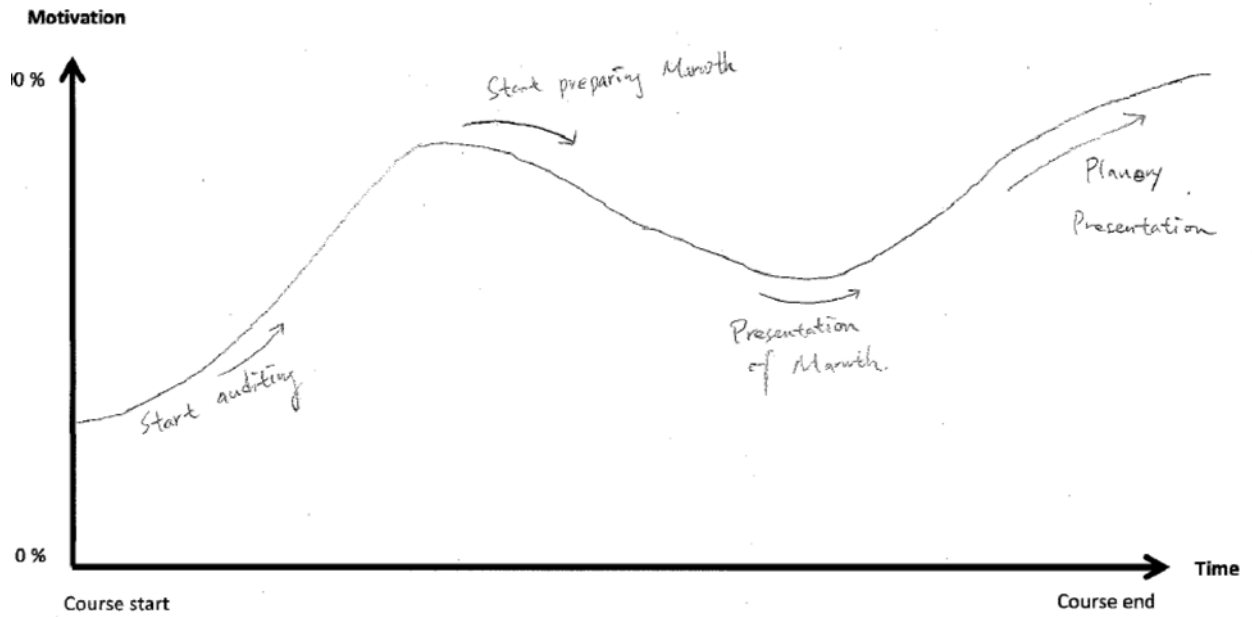


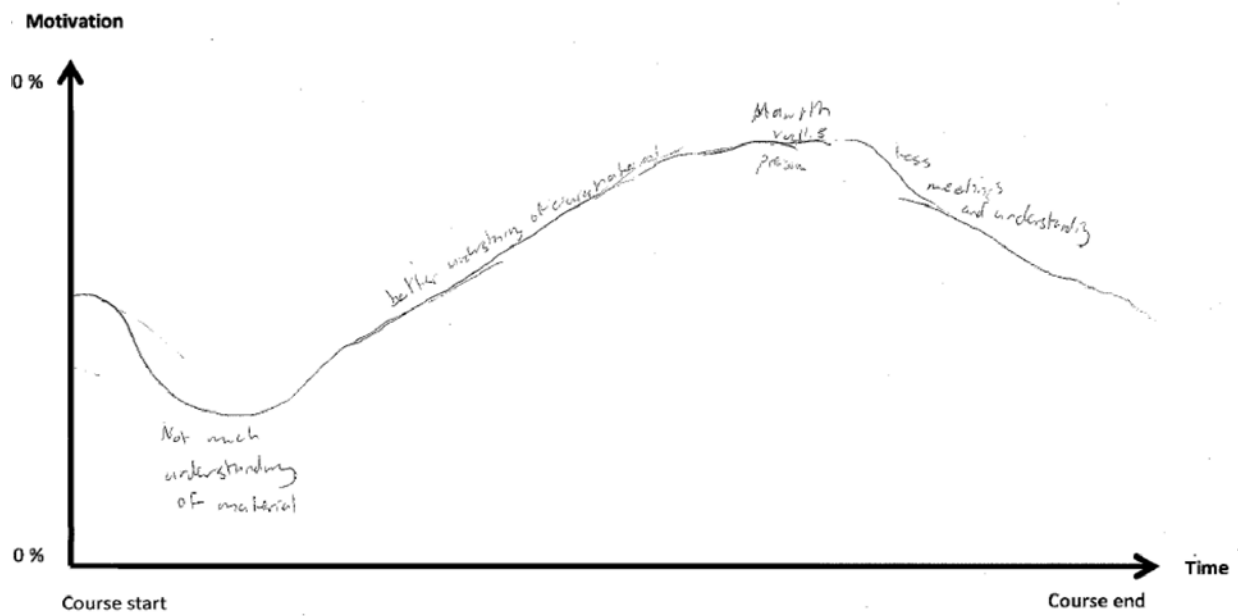
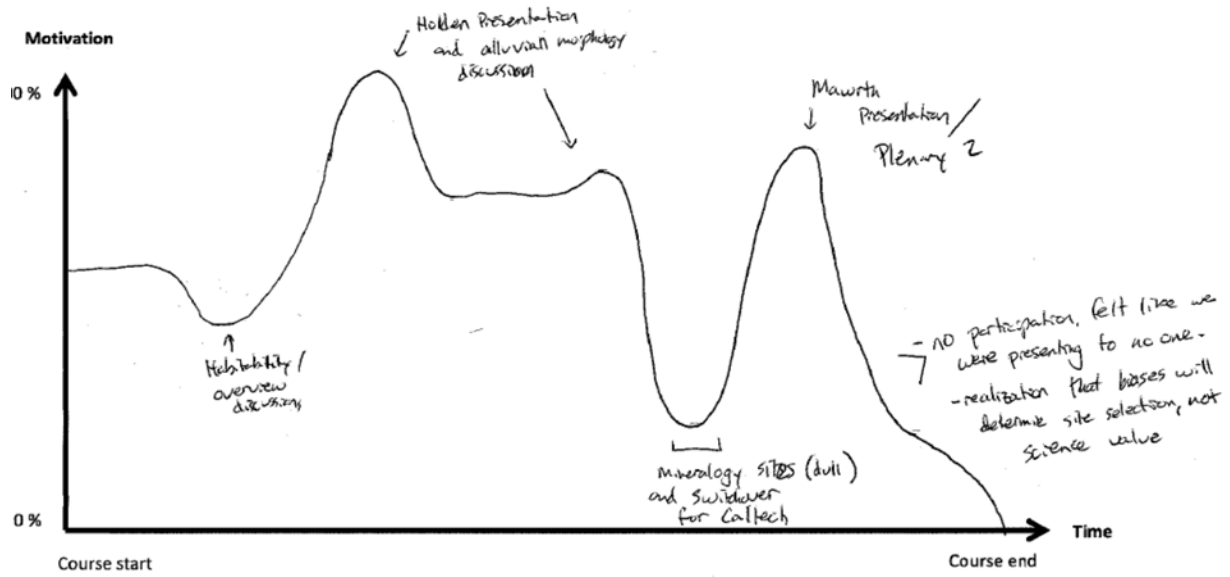
The target group of the presentations seemed to be people who already knew a lot about geology, which meant that if you had not looked up all the geology terms mentioned in the reading material of the day, you were completely lost. We started talking about sedimentary aspects, delta formations and so on before even introducing the theory.

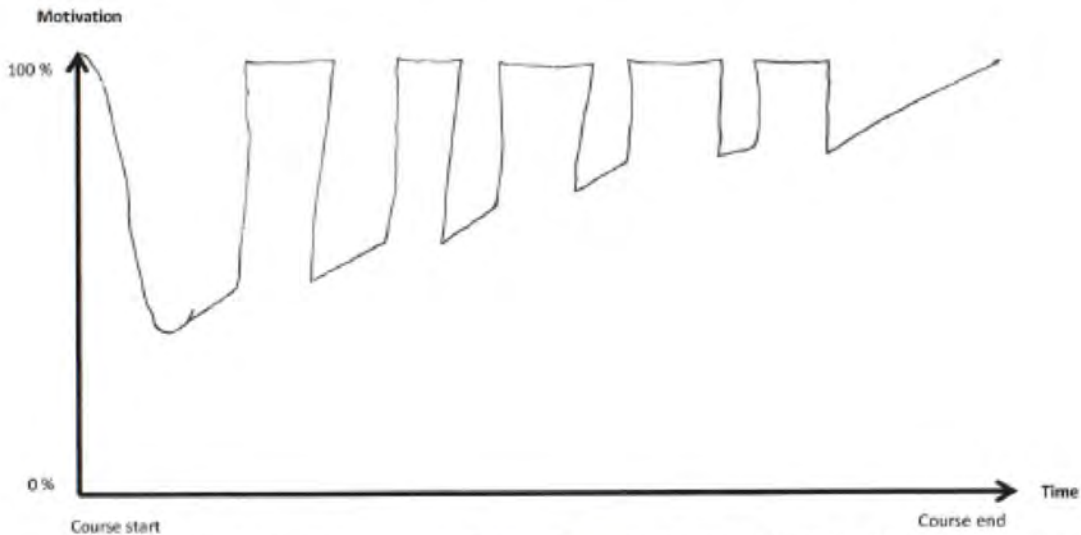
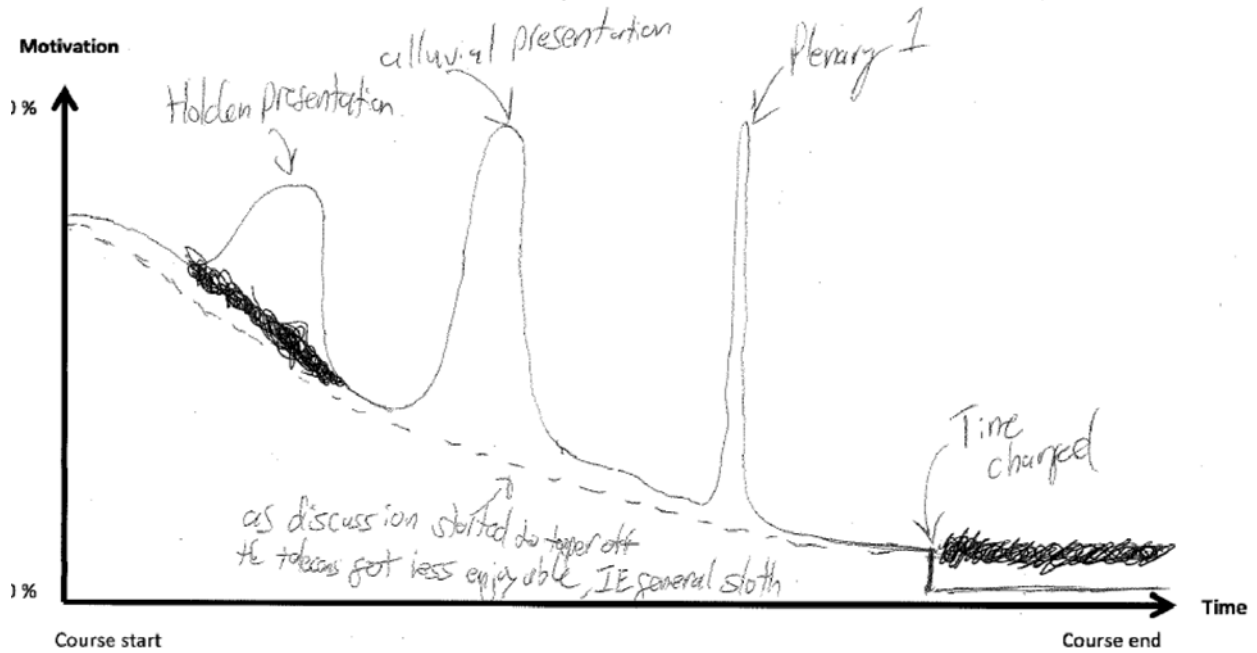
Suggestion: The first couple of weeks should be theoretical introduction to the different aspects of the geology of landing sites, so that everybody has the basic knowledge to take part in the discussion afterwards.

We were only 3 people participating at ASU, and at this point there were a lot of other things going on at the same time. The theoretical parts of the course (which I found most interesting, because the learning outcome was greater) was over.





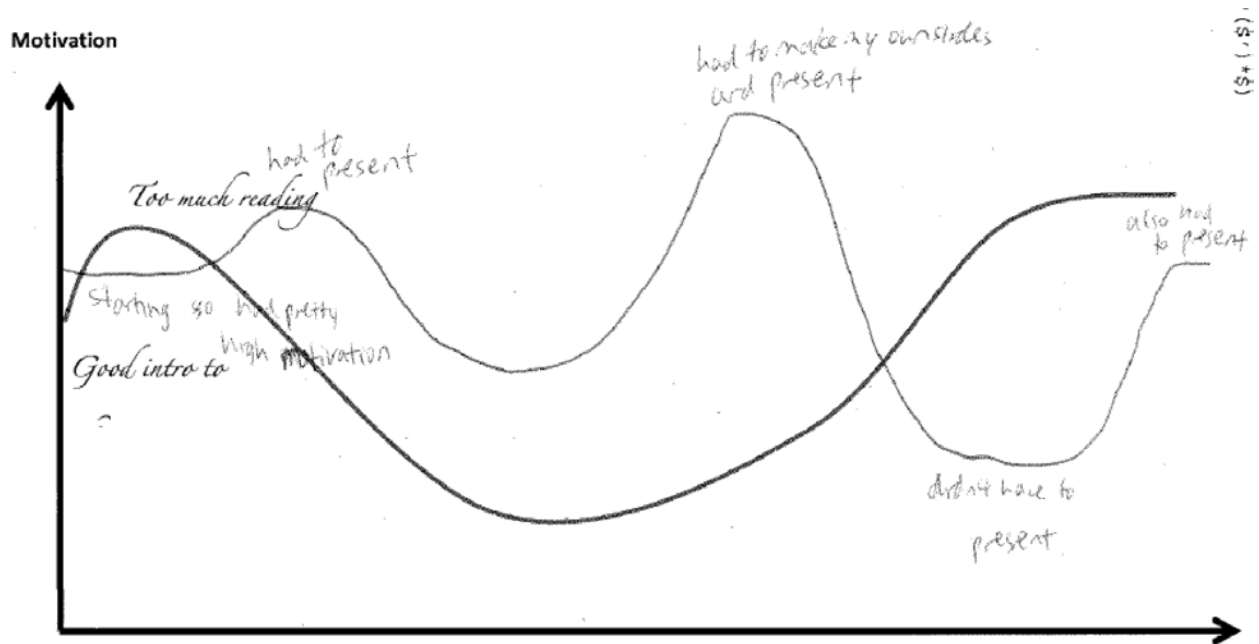
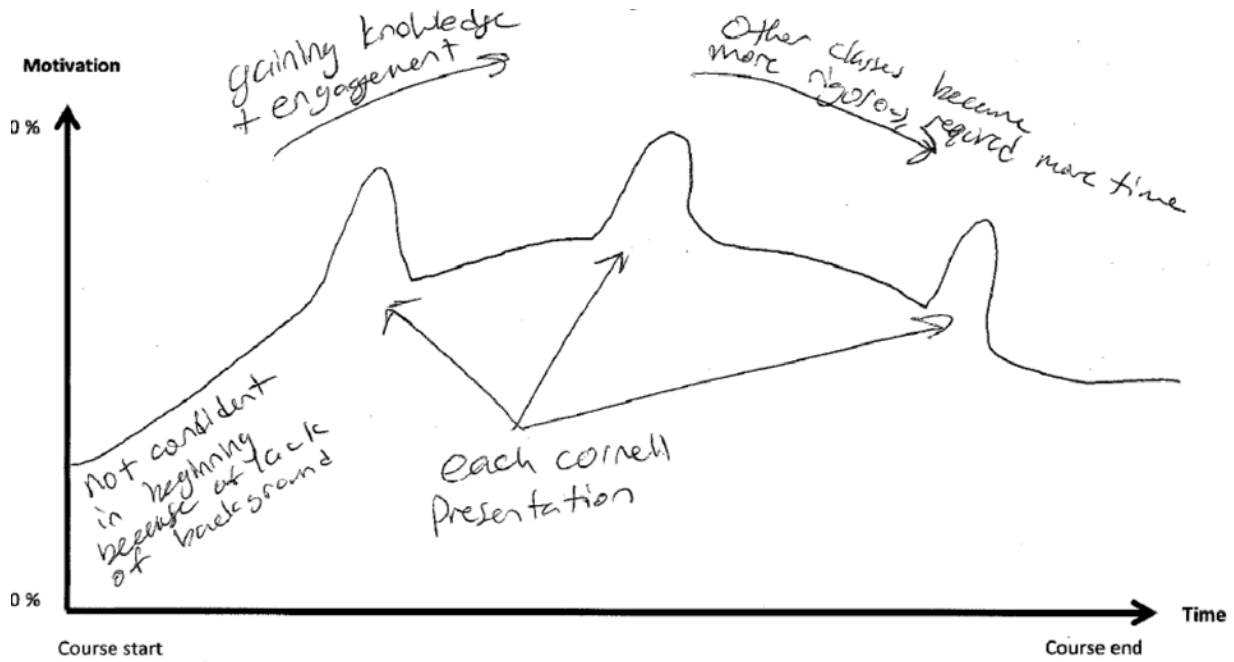


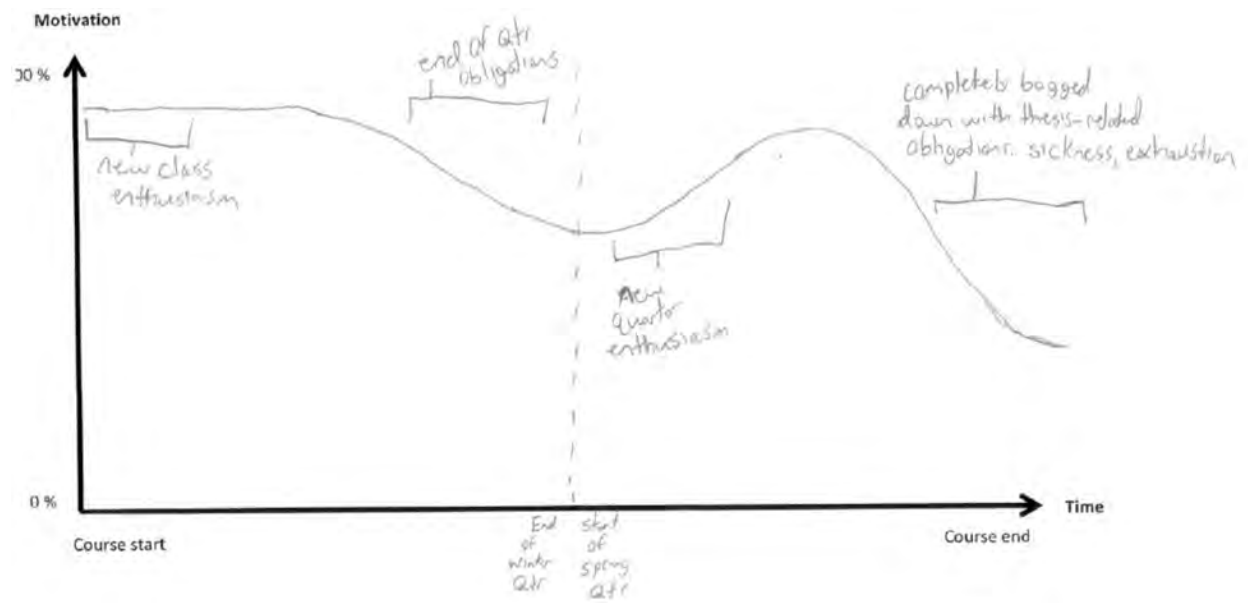
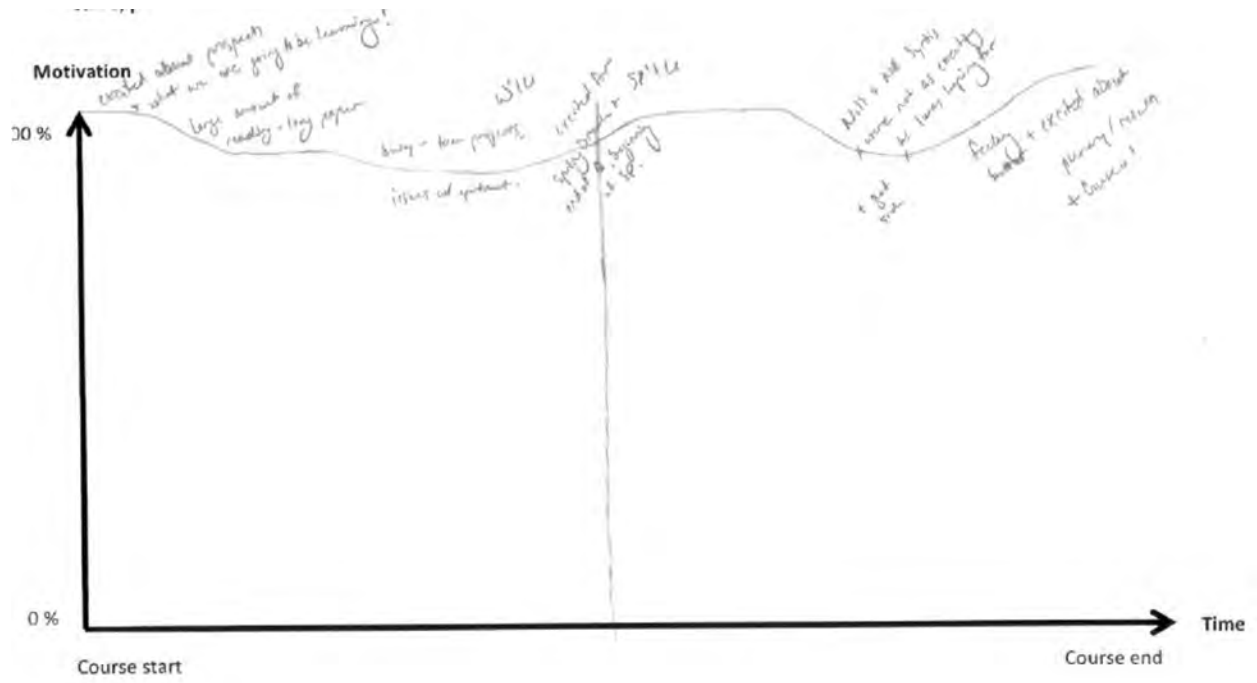


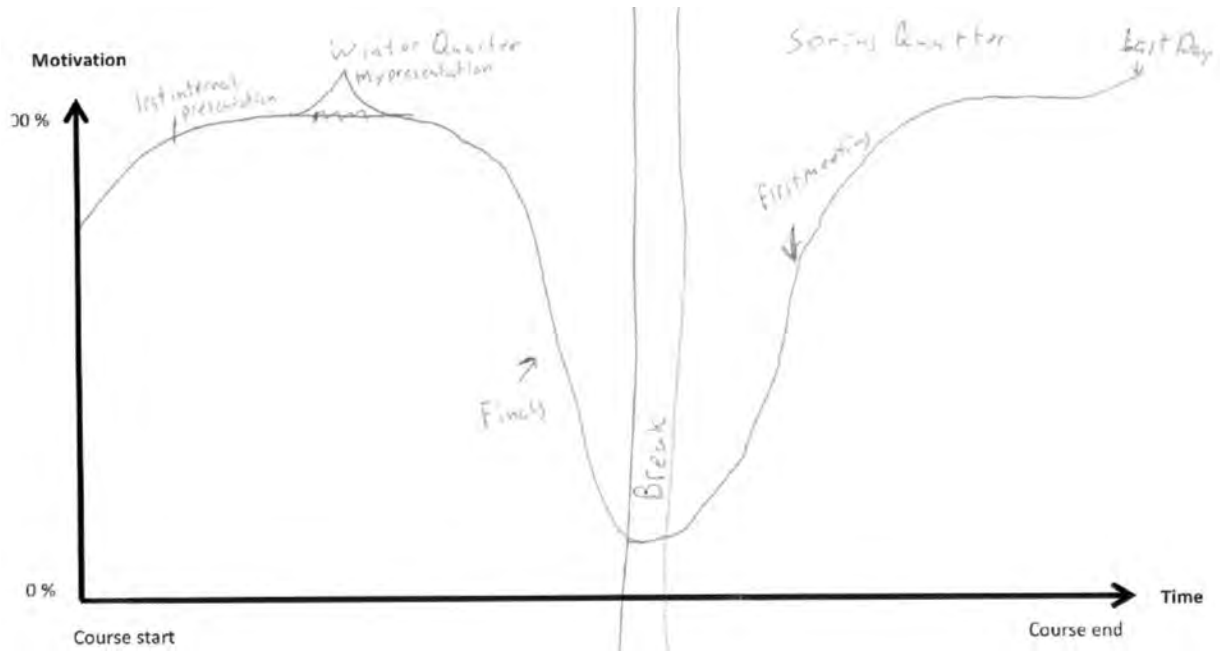
Course start

Course end

Motivation was initial high to start the new course – dropping at the beginning as the results of the technicality of some of the readings. As the semester progressed, motivation grew as the material became more familiar. Variations in motivation are also the result of group presentations (5 at Cornell) in which a greater interest was developed by more critical reading on the material in preparation for the presentation.







Curve, please make a small note to indicate what caused the change in motivation at that time.

