Learning in student projects and morphological analysis of Arctic particles

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Master thesis in Technology and Learning, degree project for the study programme *Master of Science in Engineering and of Education.*

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Abstract

This master thesis is divided into two parts, one pedagogical and one engineering.

The purpose of the pedagogical part of this master thesis was to investigate how students learn during projects. At the Royal Institute of Technology in Stockholm, three larger student projects occurred where the students themselves developed an probe that was launched into the atmosphere. The supervisors of the projects wanted to find out how the students learn during the project. The thesis includes in-depth interviews with current and former university students. In order to compare and gain new perspectives on learning, the study also included interviews with high school students to identify their corresponding experiences of learning in their final projects in Swedish upper secondary school. The result from this study shows that the students learn through participating in activities, collaboration and communication. Giving the students responsibility, a mutual goal and an important assignment makes them collaborate and learn from experience through reflection.

The purpose of the engineering part of this master thesis was to investigate samples that were collected during the Arctic Summer Cloud Ocean Study in the summer of 2008. The samples were studied by using a scanning electron microscope. The results of the thesis are consistent with former studies on samples collected in Arctic. The images from the microscope showed microgels and how the gels assembled into larger particles, particles which can play a crucial role in the formation of clouds.

Key words: CDIO, REXUS, learning in projects, experiential learning, ASCOS, scanning electron microscope, micro gels, particles, arctic marine particles
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## Abbreviations

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<td>ASCOS</td>
<td>Arctic Summer Cloud Ocean Study</td>
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<tr>
<td>CCN</td>
<td>Cloud Condensation Nuclei</td>
</tr>
<tr>
<td>CDIO</td>
<td>Conceive, Design, Implement and Operate</td>
</tr>
<tr>
<td>DLR</td>
<td>German Aerospace Center</td>
</tr>
<tr>
<td>DOC</td>
<td>Dissolved Organic Carbon</td>
</tr>
<tr>
<td>DOM</td>
<td>Dissolved Organic Material</td>
</tr>
<tr>
<td>DTU</td>
<td>Technical University of Denmark</td>
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<tr>
<td>EDS</td>
<td>Energy Dispersive x-ray Spectroscopy</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
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<tr>
<td>FEG</td>
<td>Field Emission Gun</td>
</tr>
<tr>
<td>KTH</td>
<td>Royal Institute of Technology</td>
</tr>
<tr>
<td>LAPLander</td>
<td>Light Airbag Protected Lander</td>
</tr>
<tr>
<td>MISU</td>
<td>Department of Meteorology at Stockholm University</td>
</tr>
<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
</tr>
<tr>
<td>OL</td>
<td>Open Lead</td>
</tr>
<tr>
<td>RAIN</td>
<td>Rocket deployed Atmospheric probes conducting Independent measurements in Northern Sweden</td>
</tr>
<tr>
<td>REXUS</td>
<td>Rocket-borne EXperiments for University Students</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscope</td>
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<tr>
<td>SML</td>
<td>Surface microlayer samples</td>
</tr>
<tr>
<td>SNSB</td>
<td>Swedish National Space Board</td>
</tr>
<tr>
<td>SQUID</td>
<td>Spinning Quad Ionospheric Deployer</td>
</tr>
<tr>
<td>SSC</td>
<td>Swedish Space Corporation</td>
</tr>
<tr>
<td>SSW</td>
<td>Subsurface water</td>
</tr>
<tr>
<td>TEM</td>
<td>Transmission Electron Microscopy</td>
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**Pedagogical part**

**1. Introduction**

Learning in student projects was studied for this pedagogical part of the thesis. The purpose was to create a better understanding of how students learn in larger projects. As research method, interviews with students and their supervisor were conducted. The results were compared with earlier studies reported on how students learn, which were found in the literature review.

**1.2 Background**

**1.2.1 REXUS program**

REXUS (Rocket Experiments for University Students) is a program in which university students from different European countries get the opportunity to design, develop and construct their own experiments that can be launched on a rocket at Esrange in Kiruna, northern Sweden. The aim is to provide European students with practical experience in working in space projects. In addition, students also get to experience how to work as engineers (REXUS, 2012).

REXUS program is organized and supported by an agreement between two organizations, German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish contribution makes a possibility for other students from Europe to participate, through a partnership with the European Space Agency (ESA). Experts from ESA, Swedish Space Corporation (SSC) and DLR provide the student teams with technical support throughout the project (REXUS, 2012).

**1.2.2 The CDIO approach**

In the 1980s a discussion occurred between the companies that employ engineering graduates and the universities that educated the graduates. The representatives from the companies stated that they had experienced a knowledge-drop of the newly graduated engineers whom they employed. The students often had good theoretical knowledge; they were good at solving mathematical problems and were briefed on the latest research. However, there were few who had the right skills and attitudes required by industry. The graduates had also low *hands-on*-experience using tools that engineers use in everyday life. Representatives from the companies therefore invited some universities for a discussion about the problem. The universities listened to the arguments that the companies presented and realized that the representatives had a good point. They started to collaborate in order to solve the problem (Crawley et al, 2007).

The four universities, Royal Institute of Technology (KTH), Chalmers University of Technology, Linköping and MIT (Massachusetts Institute of Technology) started to discuss what the most important goals an engineer student must have learned before he could call himself an engineer.
They wanted to build a new engineer education and began therefore to gather the latest research in teaching and learning, to get as strong foundation as possible. Based on what they came up with (what knowledge, skills and attitudes each engineer student must learn and how they would have to be taught for be able to learn this) the universities created a curriculum and a syllabus. This work culminated into an approach for educating engineering students, that got the name CDIO (Crawley et al, 2007).

CDIO stands for Conceive, Design, Implement, and Operate, and it has been developed with the purpose that students should be able to learn from disciplinary knowledge, research and technologies, but also learn those skills and attitudes which would correspond to the requirements that companies put on newly graduated students. By integrating the engineering students’ development of their personal skills with professional skills, the students are provided with the chance to both learn how to argue, communicate and collaborate, while they as well learn technical knowledge and how it is to work as an engineer. The aim is to educate students to become complete engineers. Since CDIO developed, more and more universities have begun to integrate the CDIO approach with their teaching. During the past 10 years, the cooperation has grown to include more than 50 programs in 25 different countries (Crawley et al, 2007; CDIO, 2012).

1.2 Questions
The following questions have been studied:

- In what ways does the project encourage experiential learning among the students?
- How meaningful is the project for the students?
- What attitudes and skills do the students develop?
- How does learning occur during the project?

1.3 Approach
The pedagogical part of the thesis describes how students learn by working in projects. This was studied based on written materials from the projects and in-depth interviews with active and previous participants. The study is based on different CDIO aspects to identify key activities for student learning. In order to compare and gain new perspectives on learning, the thesis also includes interviews with high-school students to identify their corresponding experience of working in projects. The goal is to create an understanding of how students learn during projects.

The pedagogical part of the report begins with a theoretical review, then a description of the methods that have been used, the results, an analysis of the results and finally, a discussion.
2. Background

2.1 REXUS project

The students work with the project over one year, usually about 18 months, as shown in table 2.1. They start the project in September by sending a proposal on what they would like to work with to ESA. If their proposal gets approved they then begin in October to research and discuss how they could solve the problem. The students develop systematically a design for the experiment.

After the students have agreed on the design, they present their ideas in front of a panel with experts from ESA. This is something that the students do after each bigger step (see reviews in Table 1). Under a review, the students have to stand in front of the panel and argue for its solution. The review panel gives the students criticism and feedback.

<table>
<thead>
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<th>Project time plan</th>
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<tr>
<td><strong>Research and design</strong></td>
<td>October to February 2012</td>
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<tr>
<td>Preliminary design review</td>
<td>February 2012</td>
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<tr>
<td><strong>Development of design</strong></td>
<td>February to May 2012</td>
</tr>
<tr>
<td><strong>Prototype testing</strong></td>
<td>February to June 2012</td>
</tr>
<tr>
<td>Critical design review</td>
<td>June 2012</td>
</tr>
<tr>
<td><strong>Probe and structure manufacturing</strong></td>
<td>July – Oct 2012</td>
</tr>
<tr>
<td><strong>Testing</strong></td>
<td>July – Oct 2012</td>
</tr>
<tr>
<td>Experiment acceptance review</td>
<td>November 2012</td>
</tr>
<tr>
<td>Integration progress review</td>
<td>September 2012</td>
</tr>
<tr>
<td><strong>System integration</strong></td>
<td>Oct – Dec 2012</td>
</tr>
<tr>
<td>System testing</td>
<td>January 2013</td>
</tr>
<tr>
<td><strong>Launch</strong></td>
<td>March 2013</td>
</tr>
<tr>
<td><strong>Data analysis</strong></td>
<td>May – June 2013</td>
</tr>
<tr>
<td><strong>Final Reports</strong></td>
<td>2013</td>
</tr>
</tbody>
</table>

*Table 2.1*: An example of a project’s time plan. Based on *Programme schedule* (REXUS, 2012).
If the students’ design becomes approved, the students can go into the next stage and start producing some prototypes which they can test before they manufacture the real ones. The students build their own equipment that they can test. However some parts of the equipments ordered from manufacturer, since these parts often need to be manufactured precisely, which only an expert can do.

Under this stage, the students get the opportunity to do much manufacturing, testing and verification of their experiment. The students discuss how to integrate all the different systems that are going to be on the experiment. For each single part that the students do, there are many iterations and meetings where they discuss what they would have to do.

The students get permission to put their experiment on the rocket after they have got everything approved from ESA. After the launch, the students analyze the data, which they hopeful have received from their experiment. They also complement their final reports with the result from the launch.

Presentations are also something that REXUS requires from the students to do. In general, there are two different kinds of presentations: outreaches and reviews.

- Outreaches are presentations that the teams do at a high school, where they present their project for the pupils. This activity has two purposes. The first one is that the REXUS program can inspire the pupils at the high schools to apply for an engineering program at, for instance, KTH. The other one is that the students get the possibility to improve their skills making presentations, a common communication method for a real engineer.
- Reviews are presentations in front of a panel from ESA. Here the project teams must explain their ideas and give arguments on why it would work. Their arguments are criticized by the panel, consisting of professors and engineers. Sometimes the teams also get feedback from the panel, in order to improve their design.

2.1.1 REXUS at KTH

The students from KTH work with the project as a bachelor or master thesis, but usually as an individual project. They are given a problem from their supervisors, a problem that could, for instance, be to collect small particles (aerosols) in the atmosphere.

After agreeing about how they would like to solve the problem, a team leader is chosen for leading the project work, and they get divided into two teams: the electrical and the mechanical team (see figure 2.1).
Figure 2.1 Organization of the student team.

The team leader has regular meetings with both the electrical team and the mechanical team, where they discuss what they are going to do. Then they also have meetings where the whole group discusses the overall picture with each other, in order to reduce misconceptions and solve problems together.

Three projects have occurred at the Royal Institute of Technology (KTH) in Stockholm, and a new project began in October 2011. The three projects handled in this master thesis are LAPLander, SQUID and RAIN.

LAPLander
The primary purpose of the Light Airbag Protected Lander (LAPLander) project was to design, build and validate a prototype of a probe that could be sent out from a rocket and collect data while it fell back to the ground. The development of LAPLander started in September 2008, and the experiment was launched in March 2010. More information about the project can be found at http://www.spp.ee.kth.se/edu/rexus2008/.

SQUID
The Spinning Quad Ionospheric Deployer (SQUID) was a project that started in the fall of 2009, and the experiment was launched in February 2011. One of the primary objectives of the SQUID project was to design, implement and test a miniature version of a wire boom deployment system, which could be used for future ionosphere measurements. More information can be found at http://www.squid-kth.se/the-project.

RAIN
The third experiment was called RAIN, which stands for Rocket deployed Atmospheric probes Conducting Independent measurements in Northern Sweden. RAIN consists of a group of students from KTH and Department of Meteorology at Stockholm University (MISU). The student group has since the fall of 2010 been working with RAIN, where the aim has been to develop and validate a technique to collect aerosol particles present in the meso- and stratosphere. More information can be found at http://rainexperiment.wordpress.com/.
2.2 Pedagogical background

2.2.1 The pedagogical background of CDIO

According to Crawley et al. (2007) CDIO has its pedagogical foundation in constructivism and social learning theories. Constructivism is a theory that describes how people learn. In constructivism, learning is a process where the learners actively construct or create their own understanding and knowledge of the world. Through experiencing things and reflecting on those experiences, new information is linked to prior knowledge. The learners are therefore not a blank slate (tabula rasa) but bring past experiences and cultural factors to a situation. According to Piaget (1976/2006) when the learners are studying and manipulating the world, both physically and conceptually, they also construct a personally meaningful picture of the world from which they can absorb. Social learning theories describe how students learn in a social context. According to Dewey (1916) communication is: “...a process of sharing experience till it becomes a common possession” (cited in Säljö, 2000, p.105).

Dewey meant that information is all around us, and we learn from each other. In order to learn, to take the information and create knowledge the students need to be active and participate in practical and communicative interactions with others.

2.2.2 Kolb’s experiential learning theory

One of the most central pedagogical theories that CDIO has adapted is Kolb’s experiential learning theory (Kolb, 1984). Experiential learning relates to Learning by doing (Gibbs, 1992) and according to Kolb, when students are given an active role in their learning process, they learn better because they are more likely to take a deep approach to learning. Experiential learning involves activating the student in the learning process, by performing different activities as exploring, analyzing, communication, creating and reflecting. Kolb summarized his research in a learning cycle (figure 2.1).

![Figure 2.2 Kolb’s learning cycle. Concrete experiences provide a basis for observation and reflection, which are summed up into abstract hypothesis and is later actively tested.](image-url)
According to Kolb (1984), the learning process can start with that the student gets a concrete experience of something, an experience that provides the student with a more or less personal connection. The student then takes the experience and starts to reflect on it: “What happened? What were the results?” From these experiences and subsequent reflections, the learner draws conclusions, which later are also tested.

2.2.3 Deep learning vs. surface learning
The knowledge that has been taught to the students must be possible to be included into their earlier knowledge structure, in order for them to remember. Marton and Säljö (1984) showed that students could have different approaches for their learning: a surface or a deep oriented approach. The two approaches are summarized in table 2.2.

<table>
<thead>
<tr>
<th>A surface approach is encouraged by:</th>
<th>A deep approach is encouraged by:</th>
</tr>
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<tbody>
<tr>
<td>Heavy workload</td>
<td>Interaction with others and collaboration</td>
</tr>
<tr>
<td>Many scheduled class time</td>
<td>Well-structured knowledge base</td>
</tr>
<tr>
<td>Lack of opportunity to pursue subjects in depth</td>
<td>Motivational context</td>
</tr>
<tr>
<td>Lack of choices over subject, methods of study and assessment</td>
<td>Learner activity and choices</td>
</tr>
</tbody>
</table>

*Table 2.2: Surface or deep learning approaches. (Based on Marton and Säljö, 1984; Gibbs, 1992; Crawley, 2007)*

Under a surface oriented approach to learning, the student tries to learn in such as a detailed and precise way as possible, in order to give back the knowledge in the same shape. This can lead to that the student gathers facts without any connection and without understanding how they relate to one another. Surface approaches for learning can also be found with university students. In fact, Gibbs (1992) showed that the longer a student had studied the more frequently was the surface approach chosen.

Students, who seek meaning and relations, try to see how the new attaches to their previous experiences. This requires the student to be active and have a desire to get the new experiences into the previously knowledge structures and thereby also restructure them.

2.2.4 Strategies for achieving deep learning
Gibbs (1992) reported five learning strategies that he considered could increase the possibility to make a student take on a deeper approach of learning:

1. Independent group work
2. Problem-based learning
3. Reflection
4. Learning by doing
5. Developing learning skills
Independent group work
According to Gibbs (1992) is it better for the students’ learning if they learn independently, the students get more freedom on how they would like to learn. They can plan when, where and how they want to study, in order to make their learning more efficient. If they also work together, they can support and learn from each other (Gibbs, 1992). Interactions and differences between the students create learning situations. The student gets also stronger in collaboration with others, they can solve problems that are more complex. “In other words, what the child can today do together with others, they can tomorrow be able to do independently” (Vygotskij, 1934/2001, p.333).

Problem-based learning
Studies made by Gibbs (1992) have shown that students who solve real problems are more prone to take a deep learning approach. By providing the students with authentic problems and encouraging the students to solve them in groups, make the students learn. Authentic problems are created by integrating subjects, which makes the students see connections. The students learn from discovering differences between each other when they work in groups and integrate with other people (Gibbs, 1992). More information about PBL can be found in section 2.2.5 Problem-based learning.

Reflection
Reflection is essential for deep learning (Gibbs, 1992). Reflection can have many different meanings, but one definition is that reflection is an active process of self-analysis where the individual tries to sort out the experience with the aim to understand and to create knowledge of them. Reflection means that an individual look back at his experiences: “How did it feel? How did it go? Why did it go well?” It can be done consciously or unconsciously. It may be a teacher who reflects on how his lecture went. It can be done in silence, in the teacher's own thoughts as he walks through the corridors, or it can be done in a group when he discusses with others, trying to understand what has happened (Moon, 1999).

Learning by doing
The origin of active learning and learning by doing can be traced to John Dewey (1859 - 1952). Dewey found that the school was too isolated from the society, what the students learned could they not use in the society. He called this for a “waste in education” (Hartman, Lundgren and Hartman, 2008, p.89, own translation from Swedish). Dewey wanted to overcome this gap by allowing the students to do activities that corresponded to what they would do in the society. For example, Dewey believed that a student, who only learns on lessons where facts are its main content, could never achieve the same familiarity about animals as a person who grew up on a farm can receive. The practical and theoretical learning should therefore be intertwined with each other; the practical work is as important as the intellectual is. According to Dewey students learn better by working with activities and solving problems, if they are correlated to what the students would do when they came out to the society. Dewey meant also that the school should provide with a safe coexistence in which students are allowed to make mistakes (Hartman, Lundgren & Hartman, 2008).
Developing learning skills
Students, who take part in deciding on how they should be taught and evaluated, develop their abilities to learn; the students learn how to learn. It is also important for the students to learn how to learn. Learning how to learn gives the students a control of their learning process. This includes that the students learn how to diagnose their own needs for learning and how to satisfy them. This type of learning is not just an essential making the learning process more effective, considering the technology- and information-intensive world in which we live today, is it also important for the students’ future professions, that they know how to learn (Gibbs, 1992; Barrows, 1980).

2.2.5 Problem-Based Learning
Since CDIO is an approach for educating students, it can be in order to describe another approach for educating students: Problem-Based Learning (PBL). PBL is one of the most common methods for educating students by arranging learning around a central problem, situation or case study, instead of visiting lectures and reading literature. The method was developed in McMaster University, Ontario, Canada during the end of the 1960’s for educating medical students. The method of PBL is based on constructivism, and the perspective that students have a built-in curiosity that makes them to learn new knowledge, which also may take them to a deeper level. The students are active in PBL and solve realistic problems, instead of passively listening to teachers during lectures. The problems in PBL are designed so that they can be solved in many different ways, engaging the students’ interests and meeting the students’ level of prior knowledge. Therefore, the problems must be realistic and complex, preferably if they are similar to those that the students would encounter in real life.

In order to encourage the students to take a deep level approach in their studies is it important to provide them with feedback and reflection on the learning process, essential in the PBL (Barrows, 1980).

In PBL learning occurs when the students are working in groups where they discuss realistic problems together with the teachers. When the students try to solve a problem, they develop and train their solving skills while they at the same time also obtain new knowledge. A problem focuses and stimulates the learning so it becomes more organized.

According to Barrows (1980) the main educational goals of PBL are:

- To develop students’ thinking or reasoning skills, like for instance solving problems and critical thinking.
- To help students become independent, self-directed learners who learn how to learn in the future.
2.2.6 The Danish study

In this master thesis, the Danish study refers a study made in 2010 at the Technical University of Denmark (DTU). The Danish study (made by Krogsbøll, Christensen & Hussman, 2010) investigated how students experience to learn in the CDIO approach; if it helps them to learn, think and work as engineers. The study was conducted because DTU wanted to find out how they can improve their education of engineers and identify which activities on DTU that best increase their students’ motivation for studying and learning. The authors were inspired and developed their study based on another study from the same university, but from 2008, in order to evaluate whether the CDIO activities generated learning as they expected, and how they could improve it (Krogsbøll, Christensen & Hussman, 2010).

In order to get qualitative feedback from the students about their views and experiences of working in projects, some students were interviewed. The interviews were based on five overall topics:

- Learning strategy
- Motivation
- Engineering
- Coherence
- CDIO

From the interviews, a written questionnaire was developed with open and closed questions, based on what occurred during the interviews. Students who had in 2010 joined a Design build course had to answer the questionnaires.

During the course, the students designed structures, installations and foundations of a house. They worked in small groups, built a digital model of the building and verified that the design satisfied technical and legal requirements. The students also made time schedules, budgets and plan the construction phases, as if the project was a real project for an engineering company (Krogsbøll, Christensen & Hussman, 2010).

The students who answered the questionnaires in 2008 build a model house, in scale 1:20 to demonstrate the best solution for a chosen area: “This could, for example, be the best insulation, the most untraditional shape, alternative building materials or the most original house.” (Christensen, Rode & Borchersen, 2009, p.2). They had also to do heat measurements and calculate the energy losses of their houses. The students worked in groups of four (Christensen, Rode & Borchersen, 2009).

The results from the study showed that interdisciplinary projects help students to learn to think and work as engineers. The CDIO activities motivated the students to study and learn. The study showed that students’ motivation for learning in a course is affected by how enthusiastic the teacher is, how well-organized the course is and how the assessment aligns with the students’ learning.
The students’ motivation is close related to how much time and effort they put into the course: “...they learn when they work, and they work to get results.” (Christensen, Rode & Borchersen, 2009, p.14).

2.3 The qualitative research interview

The interview is a method used to obtain descriptions of the interviewee's life world. The purpose, according to Kvale (1997), is to provide with qualitative texts that can be analyzed and interpreted, rather than the quantitative data that surveys can bring.

The qualitative research interview used in this study is called semi-structured, since it assumes a predetermined structure of queries in the form of an interview guide, but without being strictly according to plan as an example of a questionnaire. According to Kvale (1997) the interviewer can then actively interpret what the informants say and make continuous follow-up questions to get more details, but also to get a confirmation that the interpretation of the description is correct. During the semi-structured interview, the interviewer has a chance to explain, rephrase questions and to ask questions in any order appropriate to the situation. It is also possible for the interviewer to follow up on unexpected statements from the informant by asking follow-up questions that have not been determined in advance.
3. Methods

The work on the pedagogical part is divided into three parts: a pre-study, an implementation of the survey and a part where the results were analyzed.

3.1 Pre-study

The pre-study consisted of a literature review, the design of an interview guide and two pilot interviews. The literature review had two objectives. The first objective was to summarize the previous research of learning, with a focus on the pedagogy behind CDIO. The second objective of this study was to gain knowledge of how interviews are conducted and prepare for the implementation part. This included the development of profiles of informants, based on their reports, and an interview guide. The interview guide (Appendix A) was tested in two pilot interviews and successively revised, in order to have a solid foundation for conducting the study.

3.1.1 Collecting documents

Already in the work in the beginning of the thesis, reports were collected from each project, to provide a better foundation for the interviews. Based on the material from the documents, a basic understanding was developed of what each project had done and what problems that had arisen. It also provided a possibility of creating profiles on each student that describes for instance their assignments. The reason for this was to make the interviews more fluent and give a better understanding of how the students’ work has resulted in learning. The more information that is gathered and examined, the clearer picture can be reached.

3.1.2 Planning the interviews

Already in the planning of the interview guide, a requirement was set that the interview questions should be as ordinary and understandable as possible in order to get the informants to feel safe in their statements. The interview questions had to be linked with the key issues and the CDIO objectives, but also have an educational relevance.

The questions were developed as open-ended questions with the expectations that would lead to more detailed and descriptive answers from the interviews. These questions were simplified into question themes and reviewed as the study progressed, developing an interview guide.

Developing question themes gave the possibility to adapt the questions to the interview, depending on how the interview came out, and if it was a student, a supervisor or a high-school student who was interviewed. The structure with question themes also made it possible to categorize the various answers from the informants during the analysis.

In order for not lose any vital details for the analysis, every interview was recorded and transcribed completely. The recordings made it possible to listen through the interview carefully afterwards.
3.1.3 Selection

REXUS students

During the three REXUS projects that have taken place at KTH, around 10 students participated in various degrees during each project. In order to make the study group as relevant as possible, 20 students were selected and contacted by email. The selection was based on how involved they have been during the projects.

High-school students

To broaden the perspective high-school students were also interviewed. The expectations were that the experiences from the high-school students could create contrasts and similarities when they compared with those from the KTH students.

High-school students in the Swedish secondary upper school, do a larger project work in their final year. The project progresses for a year and aims to give the students a chance to do an independent work alone or in a group. The students can decide for themselves what subject they would like to study, how they would approach it and how to present it. Teachers encourage the students to choose subjects that the students find to be interesting, so that they have the strength to work with it for a full year. However, the topic must be related to the program that they are studying. The high-school students get a supervisor who guides them and helps them if needed. During the year, the students have regularly meetings with the supervisor; where they check off with what they have done so far, what they have to do, and if they would need some help.

Supervisors

To complement the interviews with the student groups, two interviews with two supervisors from REXUS were also conducted. Because they have been involved in all three projects, they possess valuable knowledge about how students have learned and what problems they have experienced. Since these interviews had a little bit different perspective than the student interviews, the interview guide was revised. However, in order not to affect the study too much, these interviews were conducted last.

3.1.4 Ethical considerations

Before the interview began, all respondents were asked if the interview could be recorded. The respondents were informed about what the material would be used for, what rights they had and what degree of anonymity that would be used. They were also informed that the interview would meet the Swedish Research Council guidelines for conducting interviews (Swedish Research Council, 2002). The thoughts were that the respondents would both feel safe during the interviews and be as sincere as possible. After each interview the informant asked what he thought about the interview. The aim was to improve the interview technique and get the interviews to function as good as possible.
3.1.5 Limitations
Surveys as a part method could be used to supplement the interviews. But because of too few students to provide for a reliable result and time constraints within the project framework, this was not an option. However, there were already many CDIO studies involving larger surveys, which could complement the interviews. Thus the expectations of this study were that the results from the interviews could bring new perspectives to the discussion about how students learn.

3.1.6 Inter-rater reliability
For inter-rater reliability one of the transcribed interviews was codified by another person than the interviewer, using the interview guide. Some of the quotes were categorized differently, since the quotes could be seen from different perspectives or categories. The definitions and example quotes received assessment: “Good, it was a bit difficult in the beginning to understand the differences in each category, but once starting the categorization, I understood, and it got rather simple.” (Translated from Swedish).

The inter rating resulted in a revision of the categories, so that excerpts could be categorized into multiple categories. The reason for this was that several aspects could be found in a sentence from the interview that was quoted. The reliability was increased by this action.

3.2 Implementation
The implementation part consisted of interviews with nine REXUS students, two supervisors and 13 high-school students.

REXUS students
Nine REXUS students were interviewed, one by one. Skype was used as a communication media during two of the interviews, because of geography or lack of time. All the other interviews were carried out in person. Each interview was conducted as a conversation, with 15-60 minutes per individual.

High-school students
The first group of high-school students who were contacted had done their project at the House of Science (Vetenskapens Hus). The aim for their project was to study and develop solar cells. They worked in small groups of three people in each group and got the possibility to build solar cells, which made it interesting for this study. All the students who were interviewed were studying at the natural science program at Swedish senior high school (upper secondary school). The high-school students at the House of Science were contacted by email; 14 students were contacted, three were interviewed.
The second group of high-school students who were interviewed came from another Swedish senior high school, a school which for this thesis got the fictional name Stuvstorp. They studied at the social science program and had more diverse projects, all from create and develop their own company, to visit Africa and study how microcredit affects the local people. Nevertheless, they had one thing in common: they all worked in groups. These high-school students were interviewed during one of their lessons in groups of three. Nine students from Stuvstorp were interviewed.

**Supervisors**

Two supervisors from the REXUS program were interviewed individually. The interviews were conducted in person. They were conducted last in order to not affect the study too much with their perspectives.

### 3.3 Results and analysis

Each interview was recorded and transcribed verbatim (see Appendix B). The results were analyzed by following Kvale's five analytical methods, and a raster (see Appendix A) was created based on the five categories from the Danish study (Kvale, 1997; Crawley et al, 2012).

The analysis of the interviews linked the pre-study with the results. Following Kvale’s five analysis steps the transcribed material was from the interviews processed to a more easily tangible material. The categorization of the material was based on five CDIO categories that were developed in connection with the Danish study. The expectation was that since the same categories were used, the result would be comparable with the material from Denmark during the analysis (Kvale, 1997; Crawley et al, 2007; Krogsbøll, Christensen and Hussman, 2010). But only four of the categories were left during the whole process, the category Engineering was added to CDIO. The final interview guide, with categories, definitions and examples can be found in Appendix A.

When the students had mentioned something that suited with the definitions, it got categorized. For example the quote from student R3: “…I think that this kind of learning is incredibly valuable, you can learn a great deal. The potential to learn is there, however, you have to be motivated enough to want to do it” could be categorized as both Learning strategy and Motivation. After that a whole interview had been categorized, it was read again to ensure the accuracy of the categorization.

After that a couple of interviews were finished, the analytical work started by comparing the results in each category with each other. To make it more manageable some “subcategories” were developed from the material by concentrating the material in each category into central themes. The headings in the result section represent the subcategories that constituted the final categorization. Inspired by Kvale’s five analytical methods were the material analyzed by using a flow analysis to identify some key concepts that the student used, and time-based stories were developed from the material, in order to understand the context better and create coherent learning situations.
4. Results
This section presents the results from the interviews. The results describe the learning experiences that the three groups: REXUS-students, high-school students and REXUS-supervisors, have had during their projects. During the interviews with both of the student groups the interview guide (in Appendix A) was used. For the interviews with the supervisors, the interview guide got a modification; the subjects were still the same but the questions were changed. The results from all the groups were compared to each other in four different categories. The categories were called Learning styles, Motivation, Coherence and CDIO, with inspiration from the Danish article (Krogsbøll, Christensen & Hussman, 2010) within each category subcategories were developed.

4.1 REXUS students

4.1.1 Learning strategy
Learning by doing
According to the students, they learn from more different things in the project, compared to a normal course. During courses, the students learn theories through taking lecture notes, reading and listening on the teachers. In a project, the students can feel and see what they work with. According to the students, this “closeness” gives them better skills to see if a solution is possible or not.

Since there are so few people involved in the projects, the students get the chance to test many different disciplines. They get the possibility to think like a real engineer and compare different aspects of a problem. The students learn by doing and solving things. They learn by being active during the project and trying to solve problems that occur, in order to reach the goal. Quoting student R1: “You learn in the REXUS projects by doing things and really immersing yourself in problems and asking the experts how things works and doing your own research and enforced to do your own research. Yeah, it is a really, challenging and rewarding experience.”

The REXUS students have studied a couple of years at universities before the project starts. Therefore, they have previous knowledge from which they can solve new problems with. If, for instance, one of the students was going to solve an electrical problem and had earlier experiences of solving similar problems, the student could start to reflect and perhaps go back to previous notes in order to refresh the knowledge.

By working like this the student can solve problems or learn new software that are similar to earlier learned ones, by applying previous knowledge and experiences. The students build their new knowledge on their previous knowledge.
The project gives them the chance to learn and experience how to solve multidimensional problems, that does not occurs in textbooks but in the real life. These experiences give them tools for the future. For instance, after they have done the project, the students feel like it would be easier for them to create a good structure for a project; a skill that several of the students meant is necessarily for a modern engineer.

**Learning from each other**

If a student needs to learn something new, he or she can then ask for help from the other group members, older teams, the supervisors or some other external person so that the student can learn. For instance, the student could need to work in a new software program for solve a new problem that has occurred. If he or she does not have the sufficient amount of knowledge or experiences in order to learn the new software, the student could therefore ask the others for guidance.

One of the things that the students do the most is to communicate with each other. For instance, the design part is a part that involves much communication, since everyone in the project is involved in the development of the design. The students have to discuss and argue for what they think would be the best design, in order to think out the design thoroughly. These inputs take each student with them when they go back and solve their own data. As student S2 said: “One develops both by conversation and with people, and other involved and professionally... Both multicultural and everything, so you have like a journey that is incredible. Everything is with, everything that comes with not only knowledge but also personal development as well, actually” (translated from Swedish).

The project teaches them to express themselves, argue for their ideas, and express what they know and what they do not know. During the project, they are also trained in how to actively listen, how to take part of others’ perspective and how to express why they think or feel in a certain way. Communicating is one of the most important tools in the project for learning from each other. Student R1 explained why he thought that communication is important when working in the project: “Why it was important? Cause could make decisions, if you discuss it with people, with peers, it’s much easier to get through, to solve these problems that you face. If you are doing it alone, I say or we say that you can get a blind eye. When you work really hard, you try to solve something. You think you did it correctly, but you are blind. You need someone to look at it”.

According to the students, the diversity in the group is something good when they are trying to discover blind spots in each other's reasoning, spots that can lead to larger problems. If the students come from more diverse backgrounds, they can discover more blind spots. In order to reduce these spots, they try to have weekly meetings were they sits down and discuss what they are going to do. Quoting student R4: “...I basically upload the images and the parameters and then they were going to have a look and comment on that. And I would take a look at it and comment it ‘Okay, yeah that might be a problem’, so we can discuss it a little bit about it”.

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Students that come with different background and knowledge can learn from each other. For instance, when one of the students needed some help with understanding a difficult concept, he could ask the other group members for help. Then a learning situation is created and the students can learn from each other.

**Learning from the supervisors**
From the beginning the project “belongs” to the supervisors; they are more experienced, know when the deadlines are and know what the students have to do, for instance, what documents they need to write. But as the project develops, the project gets more and more owned by the students. From asking their supervisors what to do, they start to collaborate and discuss among each other how they should solve the problems. The role as a supervisor changes from being a teacher to becoming more of an advisor that gives feedback to the students. As student S1 mentioned: “I received the eviction by the supervisor whom I sat and counted too much."Now you are too academic, try to test!" That, no, but it's a good lesson. You learn a lot; it's just that you might not think so academic. But sadly this is how you learn to think very much on the courses that I have gone anyway. It gets very academic” (translated from Swedish).

**Learning from older students**
The collaborative learning that occurs in each team creates also a natural dialog between the teams. Due to that the teams’ project times overlaps for a couple of months, the teams can share experiences and knowledge with each other. For the older students, it feels like a natural thing to assist the younger teams with their experiences.

The students have the opportunity to read the previous students reports. Here they can read what the other teams did, how they thought and also find inspiration on how to do their own report.

**Learning from external sources**
The supervisors and the team members do not know everything, so eventually the students must start to search for new knowledge. This can happen by that the student searches on the Internet or in the library after literature, articles and tutorials on the subject. The students can also join new courses or contact their previous professors and teachers at KTH in order to get their questions answered. To give the students a stronger foundation in their search for knowledge, the supervisors can help them by adding their names in the request. This makes the request stronger and can open more doors at, for instance, KTH, since the supervisors have a good network with other professors.

**Learning by reflecting**
Three students also highlighted the thought that presentations, besides that they learn how to make a presentation, also makes them to reflect on their work. When they present their experiences and knowledge, they need to take on a reflective angle on what they have completed so far. They get to summarize the work and see all the things that they have done; it is like that they get a third-person picture of the situation.
Having the presentation gave student R3 more motivation for working with the project: “Yeah, definitely! The outreach allowed me to sort of take a break from the project and step back and see what I have done. I found that a lot of time, I got bogged down in the project and in some collections of details, and only looked at that, and get really stressed out and worried about how the project was progressing, and then when I did an outreach then I would be able to step back and see ‘Okay, this is what we have done so far and this is where we are and look what we actually are going to do, this is pretty cool!’ And every time I did a presentation with the kids it was very, I really enjoyed it because yeah, ‘I’m going to design something that will go on a rocket’. Yeah, it really helped; it helped me reacquaint “.

Learning by documentation
One activity mentioned in many of the interviews, the students had to document what they had done so far in the project and write reports so that projects later can follow their thoughts. This documentation was something that both the REXUS program and KTH required from the students. By writing documentations the students think that the staff wants them to reflect on what they have done on a higher level than just thinking about it. A couple of students also bring the input that if they document what they have done, the possibility to forget decreases since their memories are unloaded from the burden of remembering some of the data. During the interviews, it occurs that the students have taken with them the method of document systematically on what they have done in their current work.

4.1.2 Motivation
Motivation during normal courses
The thing that inspires the students the most in a normal course is the teacher. The teacher can make the students interested in the subject and get them to solve problems. The course material is also important for how concerned the students are in the subject. One of the students mentioned during the interview that it was the content itself, what he learned during the course that was most important. He thought, for instance, that fluid mechanic was very interesting since it could predict the flow of fluids so completely. Nevertheless, mainly the students were agreeing that teachers made the biggest difference if a course was engaging or not.

Motivation for joining the project
The students, who join the project, do it because they want to do something practical. They want to do something real, and experience how it is to work in an international team. The main motivation is that they can then train and prepare for the life as an engineer after they graduate; they see an engineer as someone who works in a multicultural environment, full of projects. Quoting student R5: “Yeah, because, ehm… I wanted to apply the knowledge that I have got, something that you actually could touch and not from the book. And I’ve always liked the idea to be in a project with students and working on something. I felt like it could give me that little extra (inaudible).”
The students are also interested in rockets, and many of them have been inspired to join the project during one of their courses at KTH: Rocket Science. One of the students joined the project because he wanted to expose himself to new situations and problems, because then he could learn how to solve them.

**Motivation during the project**

The students look at the project as an opportunity for them to create a prototype for something that is perhaps going to be used by real engineers. During the project, they develop the experiment from their own thoughts. According to the students this makes the project more fun to do; they do not just reproduce other's work and this is something that is valuable for them. The students also feel that the large mixture that the project provides them with, contributes much to make it fun to work during the project. The mixture can be described in terms of various problems, multiple perspectives and solutions. There are always many different things to do, new things to discover and learn, as student R3 mentioned: “...I think that this kind of learning is incredibly valuable, you can learn a great deal. The potential to learn is there, however, you have to be motivated enough to want to do it”.

Since there is so much to do, the students want to contribute to the project. There is also a sense of pressure or requirements that each student should contribute with their part to the project. These requirements and all other kinds of requirements; designable requirements, functional requirements, operational requirements, pushes the students to do their work and evolve. As a result of that the students want to meet these requirements, the students work for satisfying them. Especially deadlines make the students work until late nights. This means that the students indirectly develop from the requirements, or by using a more pedagogical term: they learn.

A couple of students also mentioned that activities like outreaches and reviews, can contribute to their motivation during the project. From the outreaches, they get more energy from seeing the smiles on the faces of the pupils, for whom they explain about their project for. Under the reviews for the panel, the student can also find motivation for the project. When the review panel tells them: "You cannot do this; it is too difficult for you" the students can take it as a challenge and therefore, want to work even harder.

The students say that they work because they want to finish the project; it is not just for learning new things; they also want to launch the rocket. Some of the students contributed with the perspective that they have in the back of their mind the goal of that they want to be proud of what they are going to present. These goals make them work harder.
4.1.3 Coherence

Coherence with earlier courses
The students experienced that they had enough basic knowledge to learn during the project. Three of the students mentioned that previous experiences, as for instance practical experiences from soldering, is a plus but not necessarily for completing the project. If the students do not have the right experiences or knowledge from previous education, they feel that they can learn this during the process. Two of the students mentioned that it could not be entirely different from what they have learnt in their previous education, since it is hard to learn something completely new due to the wide range of tasks that needs to be solved in a project.

Coherence with earlier knowledge
In a normal course, the students learn by reading chapters in the course material, listening to the teacher and learn systematically, chapter by chapter. The students feel like they do not have practical knowledge and experiences from previous courses, and therefore, they join the project. They have many theoretical skills, but by joining the project, they get the possibility to complement them by adding practical skills. Quoting student R4: “…but actually I´ve learnt different stuff from project and from courses. From courses is more about the theories, and let say some stuff from your papers, from the lecture notes, from your professors. So it is mainly about theoretical stuff, but in project, you learn a lot of things other than that. Like how you review your project, like step-by-step and you manage your work and the way to communicate to other people and for the project itself you learn by trial-and-errors and also from some aspects from instructions. I mean, it is more from the practice and not from the book. So that I think is the main difference.”

The students feel like they lack experiences from working in teams. Two of the students gave the input that during their previous education they have received very little training on how to work in a team. They think that this is a pity, since it would be easier for them to work during the project, if they had experienced more group work. They learn how to argue, express themselves and also that people learn and act differently; like for instance how people are affected by the decisions and orders that the leader makes, is a valuable lesson according to the students.

4.1.4 CDIO

Technical knowledge
The technical knowledge that the students talk about during the interviews, are those that they have received from working with new equipment. For instance, working in new computer software or drawing new electrical schematics. In physics, they learn about pressure, solid mechanics and aerodynamics. For example, one of the students mentioned that they learned about cotton-powder, which is a very flammable natural organic material. The students tried to use this knowledge in order to develop a system for the landing system. However, according to the students, it is rare that they learn some new technical knowledge. It is more to establish a deeper knowledge and create understanding of the practical limits that restrict the theories they have learned at the universities.
Personal and professional skills and attributes
With help from each other, the supervisors and others, the students train analytical reasoning and methods for solving problems. They also develop their understanding of how important a group is for a project work. From the overview that the project provides, the students train their system thinking. They learn to understand how their piece fits in the whole picture and how to think as an engineer by combining experimentation with modeling. As student L1 mentioned: “…And it's fun to see how much everyone really matured during the process. That they really took on the responsibilities they had and were really driving and got, I think they got a lot of confidence in what they can actually do with their knowledge” (translated from Swedish).

The students develop various skills and attitudes, both personal and professional. The students learn how important documentation is, how to balance different variables, priorities, time and resources; professional and personal skills that companies look for. One of the students also mentioned the planning aspect. He had learned to plan and organize what expectations he could have on his colleague-students.

Interpersonal skills
One thing that the students often did, while working with the project, was to work in groups. Since the students are not familiar with each other at the beginning, the group worked more by themselves then in a group. But since the students have a mutual goal, they started to collaborate more and more as the project evolved.

Students wanting to support each other characterize the group work. They complement each other and reduce each other's blind spots when working together. This collective thinking and having a mutual goal, makes the group to weld together. The students said during the interviews that this made them to learn about new people and appreciate their contributions. Instead of trying to outdo each other, the students are there for each other, and try to give each other support if someone in the group has a rough day. The students realize this and therefore, they even try to work as a team when they are going to do their presentations.

Most of the students do not have English as their native language. Since the discussion is in English, they also train to speak and write in this foreign language. They learn by active talking in English. From the multicultural perspective, the students also learn about foreign people.

CDIO
The students consider that they have to do the whole process, from conceiving the idea to the last part of operation. They conceive, design, implement and operate the experiment by themselves. The students feel that the project is their project because they answer the questions: “What should it do?” and “How should we solve it?”. As student S1 said: “…it's like the whole experience getting to work from having an idea, from taking an idea and do something about it and everything that is in between. It's something you will always have with you. Thus, an experience of actually taking it down something on paper, realize it step by step and then move on.” (translated from Swedish).
Of course, they realize that they must always fulfill the frames of requirements that ESA sets on the project. However, these requirements are rather of the type where the students’ solutions must be thought through; they must be well-argued and have a good structure. How the structure looks like and how the students should solve the problems is up to them.
4.2 Students from high school

4.2.1 Learning strategy
Learning by doing
According to the high-school students, they learn during the project by solving problems. They reason like student N1 mentioned: “We want to go to Africa, how do we get there? We would need money, how do we get money?” (translated from Swedish).

By discussing with each other and occasionally also with their supervisors, the students break the problem into smaller and smaller pieces as they start to realize what they need to do and learn more about. For instance, if the students are going to do a project work about micro credits and no one knows anything about it in the group; they need to search for information about micro credits. They can then ask their supervisors for help, talk to other teachers and/or search the web for more information.

The students mentioned during the interviews, that they now have found other ways to search for information, before they only received special arranged material from their teachers, like textbooks or presentations. Even so, for the project, they had to find their knowledge by themselves and discovered that, for instance, the librarian at the school was very valuable. Quoting student N3: “Learn to take initiative, to work, contact and call people. And that’s good for when one should look for a job. However, I would like to do even more projects, because it feels like one really develops as a person, learns to take responsibility and to take initiative. That makes one more daring”. (translated from Swedish).

The students from the House of Science searched information for their project on the web; when the web was not enough, they emailed professors around the world, from Sweden to USA. This kind of active learning, searching for information on their own was something new for them.

During the projects, the students learned from the work that they did. One of the groups contacted a company for getting a sponsor for their project. Before the meeting, they trained to answer possible questions, what they would give back in return and so on. In the meeting, they felt that they were professional and could give a good feeling to the company. According to the students, they learned in this example how to prepare for a meeting and do a skilled presentation. As student V2 mentioned: “It feels really exciting! But, it’s a bit like this ... We will hold a presentation for a school and school children, about 90 people. So it’s a bit of pressure! Then you have moved a little outside this school level …” (translated from Swedish)
Learning from each other
Since the high-school students in each group had the same background they did not learn from each other. For example, in one of the groups from the House of Science, one of the students had more knowledge about chemistry than the others. The student explained therefore, quite often for the others what happened with the solar cells. Nevertheless, as mentioned, it was rare that the students had to explain a whole subject for each other, like some of the REXUS students had to do when they explained the new software. Of course, they helped each other when someone needed help, but more common was it instead that the students discussed problems that occurred during the project among each other. Quoting student V1: “We were four, took one part each. Working on your own part, but then you wrote quite a lot together and really discussed very much, since everything fitted together. And then we tried to help each other and interpret facts.” (translated from Swedish).

In one of the projects from Stuvstorp, was it more often that they learned from each other, since the students came from various backgrounds and had different knowledge bases. One of the students did not know how to do the accounting, but his friend could learn him since the friend had studied in the economy program. On the other hand, the friend: “did not have so good analytical ability” (Quote from student N3, translated from Swedish); therefore, the student complemented and helped each other to solve problems.

Learning from the supervisors
According to the students, the supervisors functioned as discussion partners. The supervisors gave advices, explained if they thought that an idea was good enough, came with their own ideas or provide with help if the students needed to find a new contact. However, to learn something new, it was something that the students had to do by themselves.

But there is one exception, the students does not have so much experiences from working in larger projects in school. Therefore the students received in the beginning a presentation about working in a project from their teacher. It gave them a little bit more knowledge about how it is to work in a project and what they would have to do. They were also given some theoretical basic knowledge, like for instance how to develop a time plan. This presentation is valuable for the students and gives them a better structure when they finally begin with the project.
Learning from older students
The students’ schools organize so that older students, which previous have done their project works, explain for the younger students what they have done and experienced in their projects. This activity made the students start early with figuring out what they want to do, but also to get a glimpse of the possible backsides of a project; learn from older students’ mistakes. The students said during the interviews that teachers can sometimes give a too idealized picture how it is to work in a project, so the older students can go in and explain the reality for the youngsters. It gave the younger students ideas on what they can do, what they should not do what problems that can occur and so on. For example, during one of these presentations one of the groups that were interviewed got the same contact in India as the students from the year before had used.

Learning from external sources
All the student groups learned from external sources. When neither the group members nor their supervisors’ knowledge base was enough, they started to search on their own. They searched the web, made phone calls, emailed professors and contacted companies. According to the students these were the methods which they used most often. During the interviews two of the student groups mentioned that it was easier for them to learn when they had someone who lectured for them, instead of just reading. For a student group from the House of Science it was under a presentation with a professor, when they felt that they learned the most; it was then it all became clear. Before it had been too hard, since they only had scientific articles to use as information sources.

Learning by reflecting
The students must write a logbook, where they should write what they have done and reflect on their activities: "what went good, what went wrong, why did not it go well, and what can we do better until next time?" The logbook is also for the teachers to see that their students start to work in time and not leave everything to the last week.

They had also to write a larger report in the end of the project, and at least do one presentation. However, the high-school students did not see this as an activity for them to learn from. Instead, it was more of something that they had to do. One of the students mentioned though that she learned how to build a better structure for future reports and also improved her presentation techniques. Even so, she also mentioned that she did not learn in any greater extent, she might as well not have done it.
4.2.2 Motivation

Motivation during normal courses
The high-school students think that the teacher is probably most important for how motivated they are during a normal course. The teacher sets the assignments and can inspire the students to put in that extra effort to learn in a deeper way. One of the students mentioned that she likes it when they have to think by themselves, another said that he liked it when he is challenged by a very difficult problem.

Motivation for joining the project
The students from Stuvstorp selected their projects based on their interests. It is often that they get their inspiration on what to do from media, like television and/or blogs. They wanted to do a project that was concrete and could give a result. During school, there are much of reading statistics, so therefore they thought it would be fun for example to do a trip to Africa. To be able to do the trip, or something else practical would give them more knowledge and experience besides just reading.

Besides their interest in the subject and wanting to do something practical, the students from the House of Science, joined the project since they thought that the project would have a good structure. The in-advance-planned structure and schedule of elaborations, presentations and work sessions, attracted them since it could make their work easier.

Motivation during the project
The motivation that triggers the students the most to work is the chance to realize their project and for instance go to India. Their grades and exam are also, of course, something that the students see as a reward.

How the others work for the team also affects the individual student’s motivation. For instance, if one student starts to avoid working with his assignments or does not collaborate with the others, it could affect the other team members negatively, and they could also start to feel less motivated for working in the project. Since the students from the projects at the House of Science did not get the possibility to choose their group members. Therefore, they thought it was more or less a lottery if they would get a good or bad group; or in the end a good or bad grade. According to student V3: “…it depends on everything, as what group you have, what kind of supervisor. So in my case, it was poor cohesion, and so was my supervisor, I felt very uninterested. “ (translated from Swedish).

The students mentioned that the supervisors had an important role. If the team starts to lack in motivation, the students think that the supervisors should go in and try to activate the students once again. One way of solving this problem could be that the supervisors are more activated and engaged in the project. According to the students, this extra effort from the supervisor could rub off to the students. They can see how active their supervisor is and begin to feel that the project is important again. When they feel that the project is important, the students mentioned that they get more motivated for working in the project.
4.2.3 Coherence

Coherence with earlier courses
Both students from the House of Science and from Stuvstorp believed that a student from another program could do the same project, but not as well as they had done it. For instance, the students from Stuvstorp (that studied in a social sciences program) did not think that a student from a natural science program could formulate and answer questions as good as they could. They thought that the students from social science program had more training on coming up with well-formulated and specific research questions. Contrary, the students who did their project on the House of Science and studied in the natural science program, did not believe a student from a social science program could be able to understand all the chemical processes that occur in a solar cell, or that it would take much time for them to understand it.

Coherence with earlier knowledge
During the projects, the students take responsibilities much more than normal. The high-school students must take more initiatives and be more active in the project. For instance, they must contact sponsors, collect their own money and plan for the trip. Like student N2 said during one of the interviews: “The project course has given a lot more knowledge about that you have to take responsibility. In other courses, you have a teacher who hunts you, if you are late with the assignment” (translated from Swedish).

Sometimes the students from Stuvstorp felt that it was difficult to know what they should learn during the project; a normal course would have more structure. Nevertheless, the students still said that they learned more in the project then in other courses. The knowledge that they got from working on their projects was simpler to learn and easier to remember. For example, by visiting India, they could see, feel, smell and use all their senses for learning about the Indian culture, which made it easier to remember.

The students from Stuvstorp want to do more projects, because they thought that they developed much as persons during the project. They learned to take responsibilities and own initiatives. Working in the project was a truly rewarding experience, they learned much. For instance, the students mentioned that after they had finished the project, they felt that they had become braver in testing new things than before.

Nevertheless, according to two of the students from the projects at the House of Science, they felt that they spend 10 times more time on searching for information; than what they would have to do in a normal course. This makes it more efficient to learn in a course than in a project. The student explained that because of this, they did not learn much new knowledge in the projects; it was too energy-consuming. Instead, they applied previous learned knowledge into the project. Quoting student V1: “You spend so much more time; you spend 10 times more on finding the knowledge itself, before you have it. And it's terribly much work around, so it is the time when one would rather work with.” (translated from Swedish)
4.2.4 CDIO

Technical knowledge
The students from the House of Science learned about solar cells. They learned how the solar cells work, how each component suits with the others and how to build them. According to the students, they also learned about chemistry. Generally, it did not feel for them as they learned anything new. They only repeated and deepened their earlier knowledge. The students from Stuvstorp went on the Social sciences program. Therefore, it is quite hard to see what technical knowledge they have learned. As student V2 said: “... It was like not like this ‘Wow! This is something I really understood’, it was nothing like that. But it was a bit, ‘Oh, yeah, I understood well a little about’ and ‘Yes, yes, I know a bit more about this type of solar cells.’ But with my own knowledge of chemistry, thus the use of the judgment that I have, I used the one I could since before, to understand... So it was kind of not new phenomena in, that is, brand new stuff in chemistry that you learned. “(translated from Swedish).

Personal and professional skills and attributes
During the projects, the students take initiatives and test new things. Some students got the opportunity to be interviewed by a radio station, and they took it. They were very nervous about this, but they saw it as: “it was a good way or opportunity to be challenged and learn from” (Quote from student V1, translated from Swedish) and they would like to do it again.

The students thought that working with the project felt more preparing for further studies than normal courses. For instance, they take on a higher level of responsibility than before. They plan by themselves when they would work, what they would do and how they would do it. Some of the students were not used to this and did not start the project work until late in December. This meant that they only had six months to do the project in just, instead of a year. Even so, the main part of the groups started with the project in good time.

Interpersonal skills
The structure for the teamwork in the student groups was often organized so that the students worked by themselves. They had in advance planned out what each student would do and later, often at the end of each week, they would sit down with each other and try to puzzle the work together. The students develop their communicating skills by discussing solutions with the other group members, the supervisors and/or emailing some external sources. One of the groups tried to have a structure where they would integrate the group work more: “after all, it is a group work…” (Quote from student N1, translated from Swedish). According to the students, the group work has helped them realize what skills and attitudes they have to improve. Some mentioned that they wanted to be better at working in teams, others wanted to improve their presentation technique or complete deadlines in time.
The high-school students get the chance to decide by themselves what they would like to work with and plan out their work by themselves. These stages could be compared to the Conceive and Design parts in CDIO. However, the students get the opportunity to do the Implementation and Operate parts as well, depend on whether the students can realize their project, for instance, if they have collected enough sponsorship or not.

Worth mentioning is that Stuvstorp and the House of Science had a bit different arrangement of the projects. During the projects that the students from Stuvstorp did, they could decide what to do, how to do it and even how to present what they have done. One of the groups chose to write a book and others made a presentation. The students from the House of Science had a different kind of project process. They followed, for instance, a preplanned project plan on how they would create the solar cells; they had to do laboratory experiment at specific times and also to write a report on what they have done.

### 4.3 The supervisors at the REXUS program

#### 4.3.1 Learning strategy

**Learning from the supervisors**

Due to that the projects are real projects it also becomes fun for the supervisors to work with. The supervisors are watching from front row how the students learn. Due to that the supervisors are more experienced, they sometimes teach the students and develop their personal skills and attitudes. Even so, from time to time the supervisors have experienced it to be the opposite. Because the supervisors work and solve problems with the students, they also learn with them. Not only about disciplinary knowledge, but also about working in projects, how one can handle the group, how a group learns and so on. As supervisor H1 mentioned: “However, it's fun, and it gets more fun over time to work with students as we see how the project works, and then you see how much they can learn. Not even just factually, but also project work, how to manage the group, how to find oneself in the group, how to learn in the group and things like that.” (translated from Swedish).

The students give much back to the supervisors. When a complex problem occurs in the project, the supervisors also get an opportunity to learn something new, which they have mentioned to be satisfying.

**Learning from external sources**

Sometimes a problem occurs that has to be solved, and none in the team has the appropriate knowledge. The supervisors have then experienced some of the students taking own initiatives and starting to contact external sources, like a previous teacher, in order to learn more about the subject. One of the supervisors suggested that these initiatives could be a result of that the assignment stimulates the students’ needs there and then, he or she needs to get the knowledge. Sometimes the supervisors help the students by contacting professors or departments at KTH to provide the students with sufficient help.
During the project, occasionally complex questions occur that the team and their supervisors are not prepared for. For instance, it could be that they would need to know if a special type of plastic would hold for the heat that is created during the free fall. The supervisors can then provide with their connections at KTH, and they could contact external personnel at KTH. They can rapidly contact professors, researchers or senior assistant masters, which can enter the project and help the students. These can provide the students with specific knowledge and point in which direction they should search for more knowledge, or give tips on what method they should use. Sometimes the students can take contact with the professors by themselves. Nevertheless, if the request comes from one of the supervisors, then the cooperation could lead to higher levels. For instance, the students could start to do advanced experiments instead of just searching information in a book. The professors can also narrow it down on what exactly the students need to learn, to solve the problem.

4.3.2 Motivation

Motivation during normal courses
When the supervisors are trying to figure out which students that would get the opportunity to join the project, they do not look primary at their grades. According to the supervisors is it of course pleasurable if the students have good grades, but it isn’t the most important. Instead, they look after if the students have any unfinished courses. If the students have many incomplete courses, it could indicate that the student would not perform so well, since they may need to spend time with the other courses instead of the project. The supervisors want also to have a decent mixture of the students with different backgrounds; therefore, they look at what the students have done previous and what they have studied.

Motivation for joining the project
Since the supervisors understand that the students must spend many hours working with the project, the supervisors also look on what interest and motivation each student has for wanting to join the project. If the student should be genuinely interested and wanting to spend those extra hours needed to perform well that would be a plus.

Motivation during the project
Like the students, the supervisors also get their motivation from that the project is real. It is even those who figure out the research questions, what problems they want to solve and what ideas they want to test. Quoting supervisor H1: “…And that you can do things that are related to research that I want to do and then use in the, so to speak, real projects. That is of course also my motivation; if you take a purely imaginary project, then it's harder for me to justify the work for myself.” (translated from Swedish).

During the project, dropouts occur of course, but according to the supervisors the most of the cases are because of conflicts in their schedules. If one of the students does not feel so much motivated, the supervisors can help them to find new perspectives on why the project could be an important experience for the student, for instance show the curriculum from a KTH master program.
4.3.3 Coherence

Coherence with earlier courses
During their education, the students from KTH experience to work in groups. For instance, on the school of electrical engineering, the students are provided with smaller group assignments and projects during their early studies. They also do their bachelor thesis often in groups of two. Those who come from other places then Sweden, the master students, have varied experiences of working in groups or teams according to the supervisors.

Coherence with earlier knowledge
In the projects, the students solve similar problems, but they have to consider more aspects and compare them with each other, like for instance economical arguments against the strength of the equipment. The students get the chance to think by themselves and sometimes even go where the theories that they have learned at KTH are insufficient. The problems that occur in the project are of a more diverse nature than those they have been exposed to during the courses. One of the supervisors mentions that the problems that the students have to solve during a course at KTH are often sanitized. The students are given, in principle, everything; they get the data, the material and the figures. Nevertheless, the courses provide the students with knowledge and experiences of material like, for example, aluminum. As supervisor H2 mentioned: “The goal is to give students something to hook up their knowledge and learn to work with other disciplines at KTH, simply to create the engineers ... Understanding that your products have many different demands on themselves, not only make it hold” (translated from Swedish).

4.3.4 CDIO

Technical knowledge
According to the supervisors, the students strengthen and repeat their knowledge that they have received from their earlier courses. They learn what practical limits the theoretical models have. It is rare, but occasionally it happens that the student also learns completely new technical knowledge. It happens when a problem occurs that no one in the group have the proper knowledge to solve. Then the supervisors can help some of the students to receive this knowledge, by, for instance, contacting a professor from the specific fields that the problem originates from, for example, thermodynamics.

Personal and professional skills and attributes
Since the students come with different backgrounds and personalities, they develop different personal skills. Some are from the beginning already driven and motivated, while others just sit and wait to be assigned a new task which they can solve. However, according to the supervisors this is something that only occurs in the beginning of the project, by the end of the project all the students work more or less by themselves.
The supervisors also try to manage so that everyone respects each other’s opinions. It is not often a major problem, but it is important for the project that everyone both speaks and listens to each other. If someone is quieter than the others are, the supervisors ask the student straight forward: *do you have any thoughts as well?* For they have an assignment which they represent and their opinions are therefore important.

**Interpersonal skills**

The supervisors feel that the biggest challenge for them during the project is to make the students aware of that other students in the team do not learn, work or think in the same way as they do. If the students get familiar with this, then they can start to communicate more efficient. This is something the supervisors feel that they cannot control in detail; it is something the group must learn by themselves.

**CDIO**

During the interviews the supervisors describe how the students conceive and design their own idea from their own preferences. This is something that the students occasionally also do in their normal courses. But the thing that the supervisors think that their students also experience in the project is the two other stages in CDIO; namely to implement and operate. The students get a chance to manufacture and test their own equipment before they put the final experiment on the rocket.

The supervisors provide also with their experiences from the previous projects, it is they who stand for the continuity. They know where the bar must be put, in order to manage all the checkpoints that the REXUS program has developed.
5. Analysis
The structure of the analysis is to compare the results from the different study groups with each other, contrasted with the results from the Danish study and the literature. The analysis ends with a discussion of the results based on the research questions. Each question is answered from a theoretical perspective and/or by comparison with previous researches.

5.1 Comparing results

5.1.1 Learning strategy
The students from both the REXUS program and from high school do clearly learn during the project how to take responsibility, solve problems by themselves and how to collaborate. They learn how to organize teamwork, understand the differences between theory and practice and that the problems can have more than one solution. This is similar to what the students from the Danish study mentioned that they had learnt during their projects (Krogsbøll, Christensen & Hussman, 2010, p.11).

Learning from each other
The REXUS students learn more from the other team members than what the high-school students do. This can depend on that the students from the REXUS program have more diverse backgrounds. If they come from different backgrounds they also have various experiences and knowledge. Therefore, they have more knowledge from earlier experiences that they can share with each other, then if they all came from the same background as the high-school students did; variations create learning.

Learning from older students
Both student groups get the possibility to learn from older students. Since the newer student groups from the REXUS program share the same room as the older ones for a couple of months, they share experiences with each other. The high-school students’ do not get the same possibilities; they only get to listen to one or two presentations from older students. They also do not have the benefit to see what previous student groups have done. The students from REXUS can read what the previous student groups have done in detail, since they have left behind them some reports that could be found in the workroom or on the Internet. Experiences are inherited from one team to another.
Learning from supervisors
Both supervisors from REXUS and from secondary schools helped their students when they needed help. They helped with the developing the project structure and gave them tips as the project developed. If some new knowledge was needed, they helped with contacting people who could help the students. One thing distinguished the supervisors from each other was that the supervisors from REXUS selected the problem that the students would solve. They did this based on their own research interests and thus became more motivated to spend time on the student projects. This motivation made them more involved in the projects and did not become passive as some of the supervisors at the high schools did.

Learning from external sources
The high-school students are more into seeking information on the Internet and reading by themselves, then teaching each other. They have all read in the same program the last three years and have therefore learned identical. Due to this, the students have the equivalent knowledge base, and they understand each other better, since they recognize the same terms. On the other hand, if one of the students does not understand a problem, no one of the others can help either. Therefore, the students must search for more information from external sources, for instance, on the Internet or by mailing professors.

From this point of view, it might be concluded that the students from the REXUS program are more collaborative and interpersonal. They use resources that are closer, like the team members, earlier students and supervisors. According to the supervisors, the students also contacted professors or departments at KTH to seek help for solving problems that occurred.

Learning by reflecting
Reflecting was something that students from both REXUS and high schools had in form of mandatory assignments or activities. REXUS students made in general more presentations and wrote more reports. They also saw the activities as opportunities for learning, something that the high-school students did not.

5.1.2 Motivation
Motivation during normal courses
The students from the Danish study explained that good and inspiring teachers motivated them, teachers, who know everything – in practice and in theory. (Krogsbøll, Christensen & Hussman, 2010, p.8) This matches what the REXUS students also mentioned as the first thing that motivates them during a normal course. The teachers are very essential in a course; it is they who design the structure of the course, what information that would be raised and also how it should be mediated. From this perspective, maybe it is not surprising that the students find their teachers to be so important. It is the teachers who educate and are active, while the students are passive.
The Danish study summarized it quite well how their students became motivated during a normal course: “In some courses, the topic itself is the motivation, in others a good teacher and organization of the course are the motivating factors, and finally in some courses, I don’t find any other motivation than exam” (Krogsbøll, Christensen & Hussman, 2010, p.9). This perspective is also shown in the result from the interviews with the REXUS and high-school students, who mentioned that their friends, family and own interests had a strong impact on what they get motivation by during a regular course.

**Motivation for joining the project**

According to the supervisors, the students’ motivations for wanting to do the project are important to how they later perform, since their motivations make them work harder. Both REXUS and high-school students joined the projects because they were interested in the subject and wanted to do something more practical than they normally have done in school. Comparing with the result from the Danish study their students also got motivated by wanting to know how it would work in the real world.

Students both from the REXUS program and from high schools, wanted to test their knowledge and learn from a more practical point of view, instead of just reading about theoretical models and statistics. The REXUS students also joined the project, because they wanted to become more prepared for their future work as an engineer. They think that the project is a good chance to expose them for new situations and see what skills and attitudes they would need to improve, before they graduate and start to work.

**Motivation during the project**

The students from the REXUS program explained that they got their motivations from that it was a real project. They had to solve various problems from many different aspects and think about that their mistakes can ruin the launch.

This perspective was confirmed by the Danish study. However, in the Danish study, the students experienced that they learned better if there was an exam in the middle of the course, which gave them a possibility to concentrate their effort for a while and summarize their knowledge in order to pass the exam.

If the students have small assessments or deadlines before the final exam, or of the end of the project, then they would get the opportunity to summarize and reflect on what they have learned so far in the project. By working like this, they process the information that they have got during the project and develop it into knowledge. According to the Danish study, the students felt that they could use this newly learned knowledge more during the rest of the project, then if the exam were in the end.

Instead of exams, the REXUS students had deadlines, for instance, deadline for review, which made them reflect on what they have done. By comparing it with what the REXUS students said, deadlines could work as examination, which could motivate the students to evolve. The high-school students came with the perspective that other students could negatively affect them and that the supervisors could bring motivation back into the project by being more active.
5.1.3 Coherence

Coherence with earlier courses
Both REXUS students and high-school students felt that a student who applies to the project, does not need to have much practical experiences and read many courses about the subject that they work with during the project. But of course, they would have to pass a couple of courses or years at KTH or respectively at a high school. The REXUS students think that it is a plus if the student had some previous practical experiences, but it is not necessarily.

Coherence with earlier knowledge
By comparing the result from the interviews with the students from Stuvstorp, with the students who did their project work at the House of Science, it occurs that the two groups had different ideas of how much they have learned in the project, compared with a regular course. Students from Stuvstorp thought that they had learned more in the project, while the students from the House of Science thought they learned more in a normal course. Similar to how Gibbs (1992) reasons, this disagreement could originate in that the students have different opinions of what learning is and what good knowledge is.

The disagreement could also originate in the fact that the students have studied in two different programs and therefore also learnt different things. The students from the Social science program could for instance be more used to thinking about the society. They could understand which type of knowledge the companies that would hire them would need and the students have therefore other perspective on what good knowledge is. This meant that they perhaps could see if the experiences that they have received during the project work would be more valuable experience for them in the future.

One solution of this problem could be that the students get to take courses, which concern topics that relates to their projects. A better coordination between courses running simultaneously would, according to the Danish study, be to create a more dynamic learning process. Some of the REXUS students could join courses that their assignments were about. For instance, if one of the students had to design an antenna for the project, the student could be lucky and have the opportunity to join a course about antennas. The students mentioned during the interviews that this was very good. They got the best from two worlds, both practical and theoretical.

5.1.4 CDIO

Technical knowledge
The technical knowledge that the students learn about was connected to what they were working with during the projects. For instance, the students from the House of Science could learn about how solar cells work from a chemical point of view. According to the supervisors it was rare that the students learn a completely new technical knowledge. Instead, they learned to apply theoretical topics into practical problems and experience how it is like to work in a team, which is similar to what the students from the Danish study also have to learn.
**Personal and professional skills and attributes**

The students from the REXUS program learned how to work as an engineer, how to think and reason in order to solve problems that occurred. They experienced how to think about a system, how to balance different aspects with each other and how to plan their work. Compared to the high-school students, they learned because they are going to work as engineers; they learned things for their future professions.

The high-school students did not develop into a profession as the REXUS students did. Instead, they learned because they are going to work as engineers; they learned things for their future professions.

According to the supervisors, some of the REXUS students were from the beginning passive and just waiting for an assignment to be handed to them. But as the project progressed, they developed and started to work by themselves. Therefore some of the students from the REXUS program also developed as persons.

**Interpersonal skills**

The mutual goal that was set up for the REXUS project, made according to the students then to weld together and collaborate. Since the students had important assignments to do and came from different backgrounds, they felt that they could contribute to the mutual goal, and this made it easier for them to work together. This could be something that helped the supervisors with their biggest challenge, to make the students familiar with the fact that their team members do not think in the same way as they do. Through that each member in the student teams was important for the mutual goal, the students started to help rather than to outdo each other, and this could be interpreted as a step along the way to become aware of that others think differently.

The high-school students, on the other hand, did not learn from each other so much, since almost everyone came from the same program. Of course, they could have discussed problems and solutions with each other, but it was rare that they taught each other. According to the high-school students, they preferred when they could form groups by themselves. For then the students could choose members whom they knew they could work with, otherwise it just became a lottery. This was something that the Danish study also discovered. According to their students it was better for them to choose their group members for the same reasons as the high-school students. Nevertheless, as some of the students from the Danish study mentioned, it is important for an engineer to have the ability of transforming a weak group into one that performs better.
CDIO
All the student groups got the chance to conceive, design, implement and operate. The students from the House of Science did not have the same freedom in their project. It was more planned and controlled, which limited the students’ creativity in the project. However, the rest of the projects could provide for more freedom for the students. They could, within reasonable limits do what they wanted as long as they had good arguments for doing it.

5.2 In what ways does the project encourage experiential learning among the students?
In order to analyze this question, the results were compared to Kolb’s experiential learning cycle. In the interviews appeared a couple of methods for how the students learn. Sometimes the students could describe the whole process of these methods otherwise they were puzzled together by using the context that different interviews gave. These methods summarized into three types of learning in the project. Important to emphasize is that Kolb’s learning cycle continues, also after the students have tested an idea. Testing the idea gives them the opportunity to experience a new situation which they can reflect on. This cycle continues until the students are satisfied with the results (Kolb, 1984).

<table>
<thead>
<tr>
<th>Kolb’s Experiential Learning cycle</th>
<th>Type 1, Planned learning, Presentation</th>
<th>Type 2, Internal knowledge, New software</th>
<th>Type 3, External knowledge, Antennas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Concrete experience</td>
<td>Make a presentation at a high school</td>
<td>Work in a new software</td>
<td>Design an antenna-solution</td>
</tr>
<tr>
<td>2. Reflective observation on the experience</td>
<td>Discuss what to present and start to reflect what they have done before</td>
<td>Go back to earlier files.</td>
<td>Join an antenna-theory-course</td>
</tr>
<tr>
<td>3. Abstract hypothesis</td>
<td>Summarize from different perspectives and starting to compare them with each others.</td>
<td>Try to apply old knowledge to solve the new problem.</td>
<td>Start to figure out what solution would work best</td>
</tr>
<tr>
<td>4. Active testing</td>
<td>Do the presentation</td>
<td>Test the solution, by trial and error</td>
<td>Test the hypothesis</td>
</tr>
</tbody>
</table>

Table 5.1 Kolb's learning cycle (Kolb, 1984) interpreted for this study. Three different learning

5.2.1 Planned learning
Planned learning could be defined as a learning situation which the students, supervisors, the high schools or the REXUS program have planned. This type of learning can be made up of activities like presentations, working against a deadline or writing reports in different formats. As shown in table 5.1 an example of a planned learning situation could be the outreaches where the students get to learn how to do communicate and do presentations.
This stage is the first stage and has its counterpart in what Kolb (1984) would call for “Concrete experience”. The next stage of Planned learning is the reflective stage, and in the example of outreaches is it the moment when the students tries to reflect and summarize on what they have done so far, in order to do an informative presentation. This step can be comprehensive, since the students reflections could be from many different perspectives. It could be reflecting on how much time they have for the presentation, what the high-school students would be interested in and how much energy they can spend in the outreaches, in order not to jeopardize the project.

To continue the comparison with planned learning and Kolb´s learning cycle, the stage Abstract hypothesis has its counterpart in the outreach-example the moment when the students summarize what various perspectives, which they have got from the project and start to compare them with each other. During this stage, the student tries to fit the different perspectives with each other, economical with informative perspectives, time with interest and so on.

The last step, Active testing, is of course to hold the actual presentation, and verify that it works. Under the Planned learning type, the students learn in a more or less, mandatory moment. Analyzing what the students have said after describing this type of learning, they have experienced that this type of learning gave them a possibility to reflect on the project. According to Moon (1999) and Kolb (1984) is it good for the students to reflect in order to process experiences and refine it into knowledge. Therefore, it is important that the teachers and students create learning situations where the students can reflect on the experiences that they get from the projects.

5.2.2 Internal knowledge

Internal knowledge is when the students use knowledge and information that are available for the group´s combined knowledge pool. Since the group members have different educations and came from different backgrounds they also have different knowledge and experiences when entering the project. These differences create situations where the students can learn from each other. According to Kolb (1984) is it these differences between people that create learning situations. It is through collaboration that the students can share ideas and perspectives with each other. Vygotskij (1934/2001) implies that students can go beyond their current individual problem-solving abilities with the support of group members. If the students are working together they can solve complex problems from more perspectives than an individual student would be able to do.

As shown in table 5.1, one concrete learning situation for Internal knowledge could be when one of the students needs to learn a new software. The student gets therefore a concrete experience that it would have to solve which could be compared with the first step of Kolb´s experiential learning cycle. The student could then go back and reflect on if he or she has learnt something similar in earlier studies.
In the case where the student has not worked with something similar, the student could then go to the other members in the group and ask if someone of them have experiences in the new or some similar software. If so, the students could then together create a learning situation where one of the students acts like a teacher and the other as a student. The students learn from each other by showing how the software works and explaining the major steps and key functions that they normally use to solve problems. Afterwards, the student tries by himself and if another problem occurs, he could once again go back to the other group member in order to be supervised. This would eventually lead to step three in Kolb’s learning theories, Abstract hypothesis.

In this step under the learning type Internal knowledge, the student could try to apply the new learned knowledge, that he or she has received from the others, in order to solve the new problem. After a while, the student has developed such as a large knowledge base that he or she has moved on to the next stage, Active testing. On Active testing, they often use trial and error (with reflection) and create solutions for the problem.

According to the students, using Internal knowledge as a learning method put demands on the group and its members. Internal knowledge requires that the group have a good collaborative sense, that the students trust each other and are willing to share knowledge among the group. According to (Hedin, 2006; Gibbs, 1992) are learning from others in the group depending on how the individual student feels that their needs and comments are taken seriously. If the students´ needs are met then their motivation can increase.

One activity that teachers or supervisors can use for showing that the student´s comments and thoughts are important is to allow the student to be involved and formulate objectives for the project. Gibbs (1992) means that by working like this can increase students’ motivation for learning deep-oriented.

After asking a couple of the students why they are willing to share knowledge with each other, they answered with that the group has a mutual goal. Due to the lack of time, they need to trust others in the group to solve the problems. In this type of learning the students actively reflect on if it is more efficient to learn with each other, or if it is better to learn by themselves. This is something that the students need to decide from situation to situation.

5.2.3 External knowledge

External knowledge describes how students reach out from the group and contact external sources in order to get new and reliable information. Similar to the other two types, this type is also explained by using an example, as summarized in table 5.1.

One of the students mentioned a situation when one of the members in the group had to design an antenna for the project. This problem was created when the students chose a design of their experiment that required an antenna. Nevertheless, by being exposed to the problem a learning situation was created, and the student was exposed to a concrete situation, to design an antenna.
The student started to reflect on the knowledge that he, and others had, and realized that he needed a deeper and more specific knowledge than was found in the group. So after joining an antenna-theory-course, the student could start to figure out what solution would work best for the team and encapsulate how the solution would look like. After developing a reasonable solution, the student tested it. Other situations could be that the students search the web for tutorials, contact professors and/or previous teachers for creating a learning situation. This could be interpreted as the students take more responsibility in their learning process. According to Biggs (2007), students who actively search after information, are more inclined to take on a deep approach for their learning. They are starting to see what knowledge they lack and are motivated to search information by themselves.

5.3 How meaningful is the project for the students?

Looking at the results from the interviews at the category Motivation, shows that students, both from REXUS program and high-school students, joined the projects because they are interested in the subject, and that they would like to have practical experiences of what they have studied before. While reflecting on their learning in the project, the students have described the perspective that the project has had more dynamic problems and solutions than a course would have. The students need to take on more various aspects of the problems: economical, practical, simplicity, stability… and compare them against each other to find the break-even that suits them best and bring with them to the project the best-suited solution. They do not just have to find a correct answer to a question in order to solve the problem; they must also go through many different processes, for instance, discussion with each other and test prototypes, before they even know where they begin to solve the problem. According to Barrows (1980) dynamic problems that have a realistic approach, can engage the students to take on a more meaningful learning.

The students experience group work during their project. Like some of the REXUS, students thought that experiences like those are more important than the technical. They argue that they would have to work in a group when they start to work as a real engineer. They feel that it is better for an engineer to have extroverted skills than introverted. It is best to communicate and discuss solutions than alone solve the problems. One of the students also reported that he had felt that the solution usually got even better if there was good communication in the group, than if it was not. These thoughts are supported by Vygotskij (1934/2001) and Kolb (1984) which argues that a student who collaborates with others can do more than it can do on its own: "In collaborations, the child are stronger and wiser than when it works by itself" (Vygotskij, 1934/2001, p. 331) (own translation from Swedish).
5.4 What attitudes and skills do the students develop?

According to the students, they learn to communicate with each other and collaborate with the aim of completing the project in time. From the interviews, it is quite obvious that the students learn by doing activities and interacting with each other. This learning is based on that everyone participates and works for the mutual goal, getting the experiment on the rocket. This common goal creates a penetrating sense of collaborative learning. The answers from the students mediate the sense how strong this collaborative learning is. If one withholds his or hers knowledge, thoughts, comments or ideas on a problem, the whole team gets affected. Each member is responsible both for their own and other's learning, which makes a climate where the students share knowledge and experiences with each other, both in the team and with others.

The students get the opportunity to learn different methods for solving dynamic problems, which requires the students to learn how to prioritize. Like mentioned before, the students need to solve a problem from many diverse perspectives, and they get the chance to work out methods for finding the most correct solution for the context. Example of what methods the students learn of how a real engineer solves a problem, could be, for instance, how to do verifications and the importance of documenting everything, both for reflective reasons and for having relevant information within reach.
5.5 How does learning occur during the project?

How learning occurs in the projects is summarized in a matrix that table 5.2 shows. The table has four methods on how learning occurs during projects: outwards and inwards respectively formal and informal. The methods are based on the interviews.

<table>
<thead>
<tr>
<th>OUTWARDS</th>
<th>INWARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communicative methods</strong></td>
<td><strong>Reflecting methods</strong></td>
</tr>
<tr>
<td>Group</td>
<td>Documentation</td>
</tr>
<tr>
<td>Previous groups</td>
<td>Presentations</td>
</tr>
<tr>
<td>Supervisors</td>
<td></td>
</tr>
<tr>
<td>External people</td>
<td></td>
</tr>
<tr>
<td><strong>Collective methods</strong></td>
<td><strong>Personal methods</strong></td>
</tr>
<tr>
<td>Given responsibility</td>
<td>Learning by doing</td>
</tr>
<tr>
<td>Put requirements</td>
<td>Trial and error</td>
</tr>
<tr>
<td>Respect each other</td>
<td>Doing activities</td>
</tr>
<tr>
<td></td>
<td>Building on previous knowledge</td>
</tr>
</tbody>
</table>

**Table 5.2**: How learning occurs in projects. “Outwards” means that the student learn with help from others, while “Inwards” are methods where the student learn individually. “Formal” are methods that are planned, while “Informal” originates in the quality of everyday interactions. The words with the smaller font size, describes which tools that each method depends on.

### 5.5.1 Communicative methods

In the first element of table 5.2 is *Communicative methods*. Communicative methods are learning situations that are, as can be seen in Table 5.2, both formal and outwards going. It is formal because that it is regulated to the formal titles that are given during the project: student, supervisor, professor, etc. If, for instance, a student belongs to the electric team, it would be the electrical team where he primarily would look for help to learn something new; he searches for information outwards from himself. Although it might as well be that the student takes help from the supervisors, for those would, in fact, be formally more experienced than what the students are expected to be would reasonably be able to help the student, but sometimes it can, also the opposite happened as well.

Since the projects sometimes overlap and students share study rooms with each other, or that schools organize presentations for new students, it creates opportunities for the new students to learn from the students that work with a previous project. The “older” students possess knowledge and experience that can help the newer students much if they get to take part of them. The students could also contact other, external sources like professors or teachers who formally could possess the knowledge that the students searches for. Although in order to get more attention from external people, the outreach is more solid if the supervisors contact the professors, since they have more formal power than what students can do.
5.5.2 Reflecting methods

The next element of table 5.2 is Reflecting methods. The students get to reflect on what they have done and learned by solving formal tasks that the REXUS program, the supervisors or the students, have planned in advance. Reflecting is a crucial part of the learning process and it takes place inside of the student, hence an inwards method. Documentation is not only for the teachers to know what the students have done; it is also for the students so that they can reflect on what they have done and what they have learned during the project. By using reflecting methods, the learning in a project becomes more obvious and instead of just working with the project, the students can start to learn.

5.5.3 Collective methods

Collective methods in the next element are informal methods that are created through the collaboration of the students, supervisors and the REXUS program. For example, if the supervisors trust their students and give them responsibilities to solve the problems by themselves, they get to do all kinds of activities that they can learn from. The supervisors could also put requirements on the students whom they want a certain quality developed by the students, which affects what the students learn. Collective methods are outwards learning methods in the sense that they are based on how the groups collaborate and communicate with each other. Further on, the Collective methods are based on that the participants trust and respect each other, because like student N3 said during the interviews: “...if you can’t trust them, how would you know that they are doing their job?” (translated from Swedish).

5.5.4 Personal methods

The last method for learning is called Personal methods, and it is informal methods that are not planned in advance; the learning situation just happens when it happens, much depending on the student and the activity. Personal methods could be described as learning by doing (compare with Gibbs, 1992), by having activities the students build new knowledge on previous. Activities give the students possibility to for example reason and solve problems as an engineer, doing estimations and experiments.
6. Discussion and conclusion

6.1 Implications

The learning that occurs in the projects is learning that takes place between students. It is during interactions that the students become resources for each other, and this is the major difference between traditional learning in classroom and learning in projects. During the project, students are a resource for each other and help each other to learn through collective planning, collective work and collective reflection. Learning in projects is characterized by having the students to explain to each other what they know and do not know, take part of other's perspective and tell why they think and feel in a certain way. The students are trained to express themselves, but also actively listen, help and encourage each other in a process where everyone participates in solving the problems that occur. This learning is based on that everyone participate and work for a mutual goal. Each group member is responsible for both their own and others' learning.

Due to all the collective work, communication becomes relevant between the students, the students and the supervisors (or other teachers), but also between the students and the REXUS program. Like one of the students mentioned, it is important to get second opinions on your work. Because the people that come to the project have different backgrounds, it creates diversities, which can make better solutions to the complex problems that occur during the projects. Like the student R3 said: “If you’re all from the same background, then you’ll have the same experience, have done the same subjects, and you can become quite blinded to some things. You don’t consider some things and I think it is very important to make sure that you have different personalities and people from different academic backgrounds.”.

This study has contributed to demonstrate that it is the mix and the balance between Gibbs five learning strategies that create deep learning in the projects. If one of the strategies is removed, the depth and quality of the students’ learning decreases. For example, a project that has few reflective moments can lose much learning.

If the reflected element were removed from Kolb's learning cycle, experience the students an event and just create a solution that is tested in the dark; student uses a trial-and-error approach without trying to understand why things have gone wrong. This means that if a project has few reflective elements, the focuses changes from learning to manufacturing the product. To avoid that their students take on a surface approach, the school projects would encourage their students more to think further about what, how and why they have done as they have done. According to Moon (1999), student’s learning are strengthened if the students reflect and analyze themselves from a "3rd person perspective."
To continue the discussion with Gibbs five learning strategies, all the projects that have been studied, have been good on having, for the students, relevant problems that they can solve by themselves in their groups. The students get the chance to work with a real project and something that interests them.

If Gibbs (1992) responds on what students should do during a project, in order to learn deeply, respond Table 5.2 on how it works, which roads are used:

- Communicative methods are connected to Gibb's Independent group work. The students learn by integration with others: students, older students, supervisors or external people.
- Reflective methods are connected to Gibb's Reflective practice and used during the project to allow the students to reflect. It can be done by the students, for example, to write reports or make presentations.
- Personal methods are connected to both Problem-based learning and learning by doing, since the students learn from the activities that they do and therefore get a personal experience.
- Collective methods are connected with developing learning skills. It is from the collective regulations that regulate how much the students can be involved in deciding on how the learning process should occur; the students learn how to learn.

During the projects, the students can develop their learning skills. They come from an environment where everything is clarified by the teachers, to an environment where they must start searching after the relevant material by themselves. The high-school students felt to a greater degree that it was a problem, than the REXUS students did. This may have been because REXUS the students did have more experience of working independently and have thus developed more ways that they can go in order to learn. The routes that students learn are summarized in Table 5.1.

6.2 Recommendations

The comparison between how REXUS students and high-school students learn, demonstrate that there may be a good idea for high schools to mix students from different programs. This is because if the groups have a greater diversity of knowledge, and the students becomes more important for each other’s (and the project’s) development.

During the literature review, theories were searched about how learning occurs in projects. Most of the literature that was found described just how project work should be structured and not how learning occurs. The few who, however, described how learning occurred, had weak educational attachment, for example, the authors described seldom what their theories were based on. Therefore, it would be interesting if more research was put on how learning occurs in project work.
6.3 Reflection on the study

Working with surveys, the researcher can always take statistical standpoints and find strong foundation for his arguments. Although when the researchers are working with interviews, you would instead often have to create categories, putting different pieces together in order to create a story line, or actively take decisions on what is important information and what is not. The key idea of creating a successfully study with interviews as a tool, is therefore, to be open with the result and how the study was developed. This study did not find anything new about how students learn during projects; much of the conclusion can be found in the literature about how students learn in projects. Therefore, it would maybe have been better if the study were complemented by a study that follows the work in one of the projects for a half-year, or even used as the main method. The researcher could then listen to the students how they debate, argue with each other and look at what difficulties that occur in the students. The students could then also be questioned on how they reason when a problem occurs and see, for example, how their reasoning skills develop as the project progress. By using this method, the study could make more contrasts of how the students communicated with each other during the project.

This study had the disadvantage that it only could look at what students remember about the project itself and therefore, missed essential parts where the discussion about a current issue could have provided valuable information. Nevertheless, this study has been able to confirm much of the theories that the literature describes. What this study instead may lead to be to exemplify what students can learn in a project and how the learning takes place, which may contribute to increased understanding of how the CDIO approach should be applied in engineering education. To let students try out a real and scientific project, like the REXUS program, where they can work together and take responsibility, makes them to be better prepared for the life as an engineer.

This study was based on the CDIO perspective. CDIO was created with the goal of educating modern engineers. Engineers in the society of today should be good at learning new technology, working in groups, critically analyze information and understand relationships. They are also skills and attitudes that are good to learn during project work, which made CDIO to a good instrument to build upon.

During the project, the students learn working in teams, communicating, presenting, and listening. They also get the chance to generate their own product based on given parameters and requirements. The project provides them with a better understanding what limitation's theoretical subjects, such as mathematics and physics, have. That is what this study primarily exemplifies and brings in value to the rest of the society; the perspective how to create a modern engineer.
**Engineering part**

**7. Introduction**

The aim in this part of the master thesis is to study what may be found in the samples collected during the ASCOS project 2008. The purpose is to describe the morphology of the samples and compare it with earlier studies on similar specimens. A scanning electron microscope was used to find the nano-sized objects.

**7.1 Background**

Arctic represents approximately 6% of the Earth's surface. However, only four million humans live there, including indigenous people such as Inuit, Aleut and Sami (POST, 2009). The Arctic is thus a place that has been to a lesser extent than many other places on earth, influenced by humans. This makes it a good place to carry out field studies on for those who want to try to minimize the human impact on their measurements as much as possible.

The temperature is increasing most in the Arctic (Crutzen, 2006). Regular measurements of average temperature showed that the temperature in the Arctic increased from year to year twice as much as other places on earth. According to Orellana et al. (2011), are also the relationship between aerosols, clouds, and radiation more complex in the Arctic than anywhere else. For instance, low-level Arctic clouds can regulate surface energy fluxes and affect freezing and melting of sea ice. The low-level clouds play therefore a key role in the dynamics of the Arctic climate.

**7.1.1 ASCOS**

To get a better understanding of how the clouds are created and the impact from the ocean, has four expeditions to the Arctic by the name of ASCOS (Arctic Summer Cloud Ocean Study) been sent off since the beginning of the 1990s. The latest (2012) expedition lasted throughout the summer of 2008. The samples that are analyzed for this master thesis were gathered during this expedition. The expedition took place on the Swedish icebreaker Oden and lasted 38 days from 2 August to 9 September 2008. The ship drifted through the Arctic Ocean, by anchoring itself on a 3 km x 6 km big ice floe (Chang et al., 2011).

**7.1.2 Sample collection**

Therefore, during ASCOS expedition 2008, samples from the surface micro layer (SML) were collected from the water, between ice floes (open leads) by a small battery-powered, radio-controlled vessel equipped with a rotating drum. The rotating drum, partially submerged in the water, lifted up the micro layer water. The water subsequently dripped into a glass bottle inside the vessel. According to Gao (2012) the corresponding subsurface water (SSW) was collected at the same locations. Samples were also collected from the open leads (OL), through bubble bursting that occurred in the sea spray.
7.2 Questions

The following questions have been studied:

- Which different particles can be found?
- What are their size distributions?

7.3 Approach

The engineering part of the thesis begins with a theoretical background that describes current understanding of cloud formation. The theoretical background is followed by a description, on how the study was developed. A scanning electron microscope (SEM) was used to photograph objects on micro- and nanometer levels. These pictures are summarized in the result section. Lastly, the results are discussed and compared with previous studies on similar particles.
7.2 Theoretical background

7.2.1 Cloud formation
In meteorology, a cloud is a visible mass of liquid droplets, frozen crystals made of water, or various chemicals suspended in the atmosphere. These suspended particles are also known as aerosols. Water requires a solid surface, a small condensation nucleus such as dust, ice, and salt particles to make transition from vapor to liquid. In the atmosphere, this surface presents itself as tiny solid or liquid particles called cloud condensation nuclei (CCN). CCN are small particles typically around 0.1 μm in diameter that the cloud droplets can form around (Gao, 2012).

7.2.2 Clouds affecting the climate
Albedo is the ratio between the light reflected from a surface and the total light falling on it. For instance, if the albedo is 0, then the surface is dark. Instead, if the albedo is close to one, it is very bright. Freshly fallen snow has typically albedo of about 80%, which means that 80% of the solar radiation is reflected (Budikova, 2010).

“The proportion of absorbed, emitted, and reflected incoming solar radiation steers the Earth's climate system.” (Budikova, 2010) For instance, clouds affect the climate since they reflect the solar radiation back to space or keep the radiation from the earth, causing fluctuations in temperature. How much albedo clouds have, regulates how much energy that can reach the Earth´s surface. (Budikova, 2010)

The CCNs can affect the optical properties of clouds and increasing or decreasing its albedo (Crutzen, 2006), some particles can even reduce the greenhouse gases and hence the temperature increase. For example, sulfate particles can act like CCNs. An increase of sulfate particles can reduce the amount of greenhouse gas, but they can also to acid rain and therefore cause significant ecological damages (Crutzen, 2006).

“The radiative or reflective (albedo) properties of clouds strongly depend on the number concentration of aerosol particles available for uptake or condensation of water vapor at a given water super saturation. Such particles are known as cloud condensation nuclei (CCN), and their activation and growth (2) depend on the equilibrium thermodynamics by which water vapor condenses on CCN and forms a liquid cloud drop.“ (Orellana et al., 2011, p.13612).

7.2.3 Production of aerosols
Based on how the aerosols are produced they can be divided into two categories: primary and secondary aerosols. Primary aerosols are solid or liquid particles, which have been ejected directly into the atmosphere. They have their origin from land or oceans. For example, they can come from living things, such as animals, people, plants or bacteria. They can also come from non-living things, like soil or volcanoes. They are transported into the atmosphere by forces as for instance the wind, bubble bursting, wave breaking or volcanoes (New media studio, 2012).
Secondary particles originate from precursor gases that have been ejected into the atmosphere by for instance combustion of biomass, fossil fuels or emissions from volcanoes and oceans. Precursor gases can be transformed into particles by for example condensation, chemical reactions, and adsorption on other particles or absorption into water drops. (New media studio, 2012)

To form cloud droplets from precursor gases requires in practice some form of condensation nuclei, on which the gas can condensate. If there is no nucleus available, there must instead be a high humidity if the cloud droplets are going to be able to form. It must be 300-400 % over saturated, which can almost only be done in lab. One exception of these is hydrocarbons, which may go into liquid phase even under unsaturated conditions. Hydrocarbons can be introduced into the atmosphere by bubble bursting (New media studio, 2012).

7.2.4 Categorization of particles
Particulate emissions (both from man and from nature) do not consist of particles of just one size. Instead, they are composed of particles over a relative wide size range. Therefore, it is often necessary to describe this size range. Particulate matter for size distribution evaluation is measured in a variety of ways. One of the most common is to categorize the aerosols by using three categories: Aitken or nucleation mode (0.001 - 0.1 μm diameter), accumulation mode (0.1 - 1 μm diameter), and coarse particle mode (> 1 μm diameter). The sizes of the particles are shown in table 7.1, and depend on which mechanical and chemical processes they are produced by; the modes refer also to how the particles were created.

<table>
<thead>
<tr>
<th>Modes of urban aerosol</th>
<th>Sources</th>
<th>Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aitken mode</td>
<td>Combustion particles; gas-to-particle conversion</td>
<td>0.001-0.1 um; high concentration; rapid coagulation; short lifetime</td>
</tr>
<tr>
<td>Accumulation mode</td>
<td>Combustion particles; smog particles; coagulated nuclei-mode particles</td>
<td>0.1-2.5 um; slow coagulation; long lifetime; accounting for most of visibility effects</td>
</tr>
<tr>
<td>Coarse particle mode</td>
<td>Windblown dusts; salt particles from sea spray; volcano eruptions; particles from agriculture</td>
<td>2.5 – 100 um; readily settle down on surface; short lifetime.</td>
</tr>
</tbody>
</table>

Table 7.1 Modes of urban aerosols. (based on Table 2 from University of Florida (2012)).

The range of particles size formed in a process is largely dependent on the types of particle formation mechanisms present. The general size range of particles can be estimated by simply recognizing which particle formation mechanisms are most important in the process being evaluated. Similar to how important finger prints are used to identify persons, are size distributions of particles used to detect their formation process.
For instance, condensation and coagulation processes are processes that work on particles in Aitken and accumulation mode, while processes that are more mechanical produce mostly coarse particles. Particles in Aitken mode are produced by gas-to-particle conversions, which occur in the atmosphere. When they coagulate or are affected by gas vapor, they grow and can go into accumulation mode (Miller et al., 1979).

Aerosols can grow, by, for instance, coagulation. Coagulation means that two or more particles attaches together, due to Brownian diffusion or some other forces. For example, aerosols can leave the Aitken mode, by coagulation. Particles in accumulation mode are prevented by dynamics of particle growth from growing larger than about 1 μm. To get an understanding of sizes biogenic aerosols (sizes 0.3-50 μm) could be used as an example. Biogenic aerosols like pollen and spores, but also plant and animal fragments are generally in the coarse particle mode. Smaller particles as bacteria, algae and viruses fall into the accumulation mode (see figure 7.2).

![Aerosol Particle Distributions](image)

**Figure 7.1** Particle distributions (from Seinfeld and Pandis, 2006). The plots from the top to bottom present number, surface area and volume distributions for aerosols, respectively. The one at the top are a typical example of how aerosol distribution can be in Aitken and accumulation mode.

For analyzing the particles, the number distribution in figure 7.1 can be used to compare accumulation and Aitken mode in particle samples (Hussein et al., 2003; Miller et al. 1979).

### 7.2.5 Dissolved organic material

According to Verdugo (2010), the oceans have been known a long time to play a big role in affecting the climate. It holds a huge reservoir of reduced organic carbon, mostly in the form of dissolved organic carbon (DOC). Dissolved organic material (DOM) which contains DOC, consists chemically of a broad spectrum of biopolymers, including polysaccharides, proteins, nucleic acid and lipids. The oceans contain so much DOC, that it outweighs the total living biomass by a factor of roughly 200. (Verdugo 2010).
The process of bubble bursting (from Seinfeld and Pandis, 2006). Picture D shows many small film drops that take with them organic material that are on the surface. Picture F shows jet drops. Jet drops are fewer but larger and stronger.
When more particles are released in the air can the albedo of the clouds above Arctic change. According to Orellana (2011) some of these solid particles could come from the water in the open leads and become CCNs. In other words, clouds could be formed by particles produced by ice algae or other microscopically particles, which can be found in open leads.

7.2.6 Microgels
When Biggs et al. (Leck and Bigg, 2005) examined similar samples from the expedition of 2001, they discovered a diffuse and vague exposed material that held some of the particles together. This organic material looked like mucus and later got the name microgel (Leck & Bigg 2005). Microgel was suggested to be exopolymer secretions originating from dissolved organic carbon polymers (Verdugo 2010); three-dimensional biopolymer networks containing polysaccharides and/or monosaccharide. Exopolymers are known to be produced by microalgae and bacteria in sea water and is to protect the organism from toxins and to concentrate nutrients around the organism. (Chang et al., 2011). These exopolymers become more stable by being more and more entangled and/or making weak, low-energy bonds by, for instance, attaching to the ion Ca$^{2+}$.

![Figure 7.4](image)

**Figure 7.4** Polymers assembles into nanogels (taken from Verdugo (2012)).

When the polymers become longer increases the possibility that they clump (assemble) together and create nanogels. Further can these nanogels merge (anneal) together and create even larger particles (figure 7.4). The process is, however, reversible, so the particles can become smaller as well (Verdugo, 2012).

Figure 7.4 shows DOC polymers assemble into nanogels, which in its turn can anneal into microgels. But at the same time, as the figure shows, the process can go backwards as well, creating smaller and smaller objects.
7.3 Scanning electron microscope

Scanning electron microscopes (SEM) are used for looking at small surfaces. Compared to the ordinary microscope, SEM can reach considerably higher resolution since the electrons have shorter wavelength than photons with the same energy. SEM has the possibility to analyze organic and inorganic materials that have sizes ranging from micrometers (μm) to a few nanometers (nm). Similar to how an old-fashion TV works, the microscope sweeps an electron beam back and forth over the sample. The electron beam is created by an electron gun and electromagnetic fields are used as lenses that concentrate the electrons into a small beam, focused on the sample. Detectors located inside the microscope capture some of the electrons that interact with the sample. The detector transforms the electrons into electrical signals and a computer gradually creates an image of the sample that shows its topology in 2-dimensions and can give information about the chemical composition of the sample (Khursheed, 2011).

![A scanning electron microscope](image)

**Figure 7.6** A scanning electron microscope (picture from MMK, 2010).

7.3.1 General components

General components of a SEM are normally lens system, electron gun and detectors with associated electronics (Fig. 7.7). The entire system is enclosed in a vacuum-filled tube, to minimize the number of particles that the electrons can meet on their way to the sample. Shorter mean-free path is better for the efficiency of the microscope. The lens system and the electron gun affect an electron's journey to the sample. The electron gun produces electrons and the lens system consists of electromagnets that focus the beam so that it can get a tip with a diameter of 1 nm. In front of the final lens, the microscope scans over the probe by using a deflection system. SEM uses the deflection system to sweep across over the sample in a raster-like way, whereupon the electrons spread elastic or excite secondary electrons from the surface of the sample. The SEM accelerates the electrons to energies between 0.1-30 keV (Khursheed, 2011).
Figure 7.7 A schematic drawing of a SEM (inspired by Khursheed, 2011). The electron gun produces electrons, which gathers into a small and narrow electron beam (green) by electromagnetic lenses. Scanning coils move the beam back and forth (brighter green) over a rectangular area on the sample. The beam affects the sample and scatters electrons which are detected by a detector. The detector transforms the electrons to a current, which a computer can create an image from. Everything, except the computer, is encapsulated in vacuum.

7.3.2 The electron gun
The SEM that was used during the study (JSM-7401F from the label JEOL) produces electrons using a field emission gun (FEG) (MMK (Department of Materials and Environmental Chemistry), 2012). FEG consists of a cathode and an anode and emits electrons by using a cold cathode field. When a negative potential is applied to the cathode, an electric field is created between the cathode and anode. The cathode is formed as a sharp “V” and is called filament (Goodhew, Humphreys & Beanland, 2001). The electric field is concentrated at the tip of the “V” and when the field strength reaches levels of 10 V/nm, decreases the potential barrier to such an extent that the electrons can tunnel through it and leave the cathode (Goldstein, 2003). Electrons extracted from the tip of the first anode and then accelerated by a second anode to a higher potential.

7.3.3 The lens system
Since the electrons from the electron gun have a relatively wide range of different wavelengths and direction, they are too diverse for creating a sharp image. The SEM is therefore equipped with a lens system that concentrates and focuses the electron beam into a minor point on the sample. The lens system consists of condenser lenses, objective lenses and scan coils (see Figure 7.7).

The lenses are made up by electromagnetic coils. When the electron beam passes through a lens, the electrons are affected by electromagnetic forces that can change the electrons'
motion. The condenser lenses clean up among the electrons, so that those electrons with wrong kinetic energies are filtered away or their direction changed. The condenser lenses make the electron beam monochromatic, which means that the electrons that reach the sample all have the same wavelength. If the beam would not be monochromatic, then the electrons could go differently deep in the sample. This would create an incorrect picture. The electrons are concentrated together into an electron beam.

The condenser lenses become stronger when a larger current is applied in their coils. Generally speaking, the stronger the condenser is, the narrower gets the beam that strikes the sample. However, at the same time the intensity of the beam gets weaker since more electrons are filtered away (Goldstein, 2003). After passing through the condenser lenses, the beam reaches the objective lenses. The objective lenses are there to focus the picture and form a small probe. Lastly the beam passes through pairs of scanning coils. The scanning coils are also recognized as deflector plates in the electron column, typically located in or after the final lens. They deflect the beam in the x and y axes so that it scans in a raster pattern over a rectangular area of the sample surface. By adjusting the working distance (the distance between the sample and the final lens) the focus can be changed.

7.3.4 Interactions with the sample
When the primary beam penetrates the surface of the sample, it can interact with atoms on different depths in the material, emit photons (or X-rays) and scatter electrons. There are three types of electrons that can be scattered: secondary, backscattered and Auger electrons (compare with figure 7.8). In SEM are secondary and backscattered electrons used for imaging samples, since their energies primarily depend on of what kind of topology the sample has (Goodhew, Humphreys & Beanland, 2001).

![Figure 7.8 Emitted signals. (from Khursheed, 2011). The primary beam is the incoming electron beam and R is the interaction volume (see section 7.3.6 for more information).](image-url)
Secondary electrons give information about the topography of samples. (Swapp, 2012) They are defined as electrons with energies less than 50 eV and have been produced by inelastic collisions and escaped from the surface of the samples (Khursheed, 2011).

Backscattered electrons are generated by multiple elastic interactions with specimen atoms, and they have been scattered back from deeper levels than secondary electrons. They are important to collect, since they provide information about contrasts in compositions in inhomogeneous samples (Swapp, 2012). Elements that have high atomic number (heavy elements) backscatter electrons more strongly than light elements (low atomic number), and thus appear brighter in the image. Backscattered electrons are used to detect contrast between areas with different chemical compositions. The electrons can have energies from 50 eV up to the same energy as the primary beam (Khursheed, 2011).

![Electron Spectrum](image)

**Figure 7.9** The electron spectrum of electrons that leave the spectrum. SE stands for Secondary Electrons and BSE stands for backscattered electrons (the figure is from Khursheed, 2011).

### 7.3.5 The detectors

Some of the electrons that interact with the sample are captured by detectors located inside the microscope. In SEM, the detectors can provide information about the chemical composition and topology of the sample (Khursheed, 2011). In order to provide the detectors with as many secondary and backscattered electrons as possible, the sample must be conductive. Biological samples are often not conductive. A method for overcoming this problem could be to prepare the sample with a thin metallic layer before it goes into the SEM. The thin metallic layer makes the current flow through the material; the detectors can collect electrons and produce an image. Further, if the sample becomes conductive, then a voltage difference can be maintained between the sample and the detector. The voltage difference makes it easier for the detector to attract secondary and backscattered electrons since they are negatively charged. However, the voltage that is applied on the sample, can’t be too high since it would then prevent the electron beam to interact with the specimen.
Secondary electrons are detected by a scintillator system known as Everhart-Thornley detector. When electrons go into a detector, they strike a scintillator and light emits. The light travels through a small pipe and into a photomultiplier tube, which converts the photons into pulses of electrons and thus, a small current is created. The detector transforms the electrons into electrical signals. The signals are amplified and a computer creates gradually an image of the sample. The image shows its morphology in 2-dimensions and can give information about the chemical composition of the sample. Each pixel in the image corresponds to a position on the sample in the microscope (Goodhew, Humphreys & Beanland, 2001). The brightness of the signal that is detected by the computer depends on the number of secondary electrons reaching the detector. The more electrons that enter the detector, the brighter become the image. (Goldstein, 2003).

The Everhart-Thornley detector, which is positioned to one side of the specimen in JEOL, is ineffective to detect backscattered electrons. Backscattered electrons have higher-energy levels than secondary electrons and can therefore easier over win the attractive forces from the detector. Instead backscattered electrons are collected by using a doughnut-shaped detector. The doughnut-shaped detector is located along the electron beam, maximizing the probability of collection since the solid angle is maximized. Combining this information with the information given from Everhart-Thornley detectors an image is created by the computer. If the focus is set correctly, then an image that shows the topography in the sample and in some extent also the chemical composition can appear on the computer screen (Goldstein, 2003).
### 7.3.6 Interaction volume

Interaction volume is the region which electrons from the electron beam penetrate the specimen into. Even though inelastic scattering is generated within the interaction volume the electrons do not get detected unless they escape from the specimen. Therefore, to create high-resolution images, it is important to get as many electrons (that have interacted with the sample) as possible back to the detector.

![Interaction volume](image)

**Figure 7.10** Interaction volume (the figure is from Khursheed, 2011). A cross-section of a sample that is 1 μm thick. By using Monte Carlo simulation programs can simulate how the primary beam scatters inside the sample, depending on different voltages.

Figure 7.10 shows a cross-section of a sample that is 1 μm thick and how different thickness of various specimens is affected by different beam energies. By using Monte Carlo simulation programs how the primary beam scatters inside the sample can be simulated, depending on varying voltages. If the energy of the beam is too high, all the electrons can go through the sample, and it becomes difficult to detect secondary and backscattered electrons that can give information about the sample's topology. On the other hand, if the beam has too low energy, the electrons would not affect the sample, and just a black image is shown on the computer screen. Therefore, it is important that the energy of the beam is coordinated after the sample type and its thickness; else it becomes difficult to create an image of the sample’s topology. According to Khursheed (2011) depends the interaction volume as:

\[
R = \frac{0.02676 A V^{1.67}}{Z^{0.889} \rho} \quad (\text{μm})
\]

where \(R\) is the interaction distance, \(V\) is the primary beam voltage, \(A\) is the atomic weight, \(\rho\) is the mass density, and \(Z\) is the atomic number.
7.3.7  Charges in the samples
When a sample is affected by an electron beam, electrons go into the sample and out through the electrical ground of the SEM, and some go to the detectors. There is also a buildup of excess electrons on the surface of the sample. Since the electrons have charges, the electric field between the detectors and the sample can change. This electric field can affect the image from the detector in unpredictable ways and deflect the electron beam. In addition, charges collected in the sample can cause the images to become misleading. Since some items may collect charges faster than others, they appear brighter than they normally would be. Generally speaking, the more non-conductive material there is in a sample, the more charges become a problem. Some possible solutions would be to turn down the beam voltage (lower voltage decreases the sample potential) or coat the samples with a conductive layer, like gold or platinum (Goldstein, 2003).

Gentle beam, a beam deceleration technique that is integrated in JEOL JSM-7401F, can be added over the sample to reduce the damage from the beam and remove charges from the sample.
8. Methods

8.1 Experimental setup

During the first stage, pictures of the samples were taken with a SEM of the type JEOL JSM-7401F. During the work, the same process was used. First the samples were placed on a special designed holder. The holder was inserted in the airlock and subsequently in the microscope where a vacuum was created.

![Figure 7.1 SEM grid. The figure shows how the SEM grid looks from above.](image)

Since the samples have a grid with a mark in the middle as in figure 7.1, the samples could be divided into four quadrants making a coordinate system. Each of the quadrants was named a, b, c and d after their position compared to the mark in the middle. For each of the samples, one quadrant was selected, and by gradually moving the beam diagonally outward (first square a1.1, then a2.2, a3.3 and so on) seven squares were photographed for each sample. Each square was photographed with about 25-30 pictures of x10k magnification and about 20-30 pictures of x40k magnification. After that a square got complete, also a picture of x1k magnification was taken, so that the whole square was in the picture. The working distance was adjusted to 3.5 mm, the sample height to 1.9 mm and the voltage to 3 kV. With Gentle beam set to -2kV over the sample, made the total voltage of 1 kV. For each new square was the astigmatism adjusted to have as good focus as possible. With this procedure over 1200 pictures were taken on three different sample types.

8.2 The samples types

There were three different sample types that were analyzed, SML, SSW and OL. They were collected during ASCOS expedition of 2008. The collecting methods of these samples are described in section 7.1.2 Sample collection.
9. Results

The structure of chapter 9 is based on the research questions. All questions are answered with what was discovered on the samples.

9.1 Which different particles can be found?

The samples that were analyzed with the SEM were taken from SML, SSW and OL. Each of the three sample types categorized considering which objects that occurred on the photos that were taken during the sessions. Each category is exemplified with two pictures and then followed with an explanation of the morphology of the category; how common the objects were in the samples, what size they have and how they look like. When the pictures are not taken with the same magnification, the one with the smaller magnification are located to the left.

9.1.1 Surface microlayer samples (SML)

The samples that were taken from the SML had small particles, ranging from some few nanometers up to 1 μm. On the other hand, the samples had many of these particles and other objects, as for instance micrometer sized objects shaped as circles or S.

Nanoparticles

Nanoparticles, as shown in figure 9.1, are like the name tells particles that are smaller than 100 nm. They occur both as single particles and grouped particles. Grouped particles of nano-size can be grouped into a pattern (see Shimmer or Strings) or into more chaotic systems like the figures above. Due to their sizes, Nanoparticles were difficult to detect, but they were the most common particles.

![Figure 9.1 Nanoparticles. Left: square a(2,2) of sample Wet 49. Right: square a(3,3) of sample Wet 49.](image-url)
Small grains
Small grains (as exemplified in figure 9.2) are smoothly shaped, but one can still distinguish them from the background, meaning that Small grains are distinct particles and not as a pile of dough. The sizes of the grains are ranging from about 100 nanometers up to 300 nanometers. Small grains are easy to locate because they are lit up in bright white when they are exposed and charged by the electron beam, estimated Small grains were the second most common particle found in the SML samples, after Nanoparticles.

![Small grains](image.jpg)

Figure 9.2 Small grains. Left: square a(3,3) of sample Wet 49. Right: square a(1,1) of sample Wet 49.

Strings
An object from the category Strings can sometimes go over a whole SEM grid square, as the figure 9.3 shows. When Strings is charged it shines up as a white cream-like substance, which can sometimes contain particles that lie on top. The white cream substance is distinct, but at its ends the substance gradually becomes smaller and less bright. Strings are circular patterns and can be long, up to 50 μm. Almost each square in the SML samples included a couple of Strings.

![Strings](image.jpg)

Figure 9.3 Strings. Left: square a(4,4) of sample Wet 49. Right: square a(5,5) of sample Wet 49.
Shimmer
Shimmer is like Strings formed as circular patterns, but does not have the characteristic flour-like cream. Instead, it has diffuse paste that could be found at the edges on Strings, creating a dim-like pattern. Small, nano-sized particles are also available in Shimmer. Shimmer is like Strings relatively large, ranging over dozen micrometers. Almost each square in the SML samples included a couple of Shimmer. Shimmer are exemplified in figure 9.4.

Mucus
Mucus is spots of the white flour-like substance similar to what could be found in Strings. However, in contrast to Strings, objects in the Mucus category are not formed into a circular-shaped pattern. Instead, they appear in a more or less chaotic way, like the figure to the left shows. When an image at higher magnification was taken on a Mucus object, it was impossible to get a good focus on the object, although the focus was adjusted several times. This suggests that Mucus objects are flat. The objects in the Mucus category are ranging from a few nanometers up to a few micrometers.

Figure 9.4 Shimmer. Left: square a(2,2) of sample Wet 49. Right: square a(2,2) of sample Wet 49.

Figure 9.5 Mucus. Left: square a(5,5) of sample Wet 49. Right: square a(1,1) of sample Wet 49.
**Slime clumps**
Slime clumps have a more “glowing” appearance than Mucus, which creates a more sense of three-dimensional objects, showed in figure 9.6. Smaller Slime clump-objects are more transparent than both larger Slime clump-objects and Mucus objects. The sizes of Slime clumps range from about 10 nm up to 1 μm.

![Figure 9.6](image)

**Exotic objects**
Figure 9.7 shows to the right objects which got the name Crystals. Crystals are in the same sizes like Grains, but they do not have the characteristic smoothness as Grains. Instead they are sharp looking particles.

To the left in figure 9.7 is a circular pattern that looks like a bubble, with diameter of about 5 μm. Only two bubbles were discovered. Inside of the circle is a white flour-like smear, a little bit more transparent than Mucus.

![Figure 9.7](image)
9.1.2 Subsurface water (SSW)

The samples that were taken from the SSW had, (like SML) small particles, ranging from some few nanometers to 1 μm. Also in the SSW samples, Nanoparticles, Small grains, Strings, Mucus, Slime clumps were found. But they looked a bit different, for instance String-objects were not formed as an S or like an 8 (like in SML). Instead they were formed like a C and had thicker particles inside its strings. Therefore, to see similarities and differences, figures are added to each category. If something is different in a SSW category, compared those from SML, the differences are explained. One of the objects which were found in SSW was not found in SML, namely Shimmer. Instead Small fractals were recognized so often that it got a category of its own.

Nanoparticles

In SML Nanoparticles were found. Here as well they were smaller than 100 nm and occurred often. Even so, due to their sizes, they were hard to discover. Sometimes they could be found in Strings like figure 9.8 shows to the right.

![Figure 9.8 Nanoparticles. Left: square a(2,2) of sample Wet 50. Right: square a(6,6) of sample Wet 50.](image)
**Small grains**
Small grains were also found, as shown in figure 9.9. They occurred more often in groups than in SML. Their sizes ranged from about 100 nm up to 300 nm.

![Image of small grains](image)

**Figure 9.9** Small grains. Left: square a(1,1) of sample Wet 50. Right: square a(1,1) of sample Wet 50.

**Strings**
Strings that occurred in the SSW samples was not as smooth as those from the SML samples, instead they had discontinuities in them. Just a few were smooth like those which were found in the SML samples. While Strings in SML samples were like S-curves or 8s, those found in SSW were more C-shaped, like figure 9.10 shows on the left. Worth to mentioning is that they often occurred with small particles inside them, like the right part of figure 9.10.

![Image of strings](image)

**Figure 9.10**, Strings. Left: square a(5,5) of sample Wet 50. Right: square a(4,4) of sample Wet 50.
Mucus
Mucus was not found in SSW as often as in SML. Instead, it occurred in small dots like the figure to the left or like a bigger dot like the figure to the right. In SML, the sizes of Mucus ranged from a few nanometers up to micrometers, as it occurred in smooth Strings.

Figure 9.11, Mucus. Left: square a(2,2) of sample Wet 50. Right: square a(5,5) of sample Wet 50.

Slime clumps
In SSW also Slime clumps was found (as shown in figure 9.12). They occurred approximately as often as those that were discovered in the SML samples, frequently discovered along with Small fractals (see the next category). Slime clumps-objects ranged from a few nanometers up to 500 nanometers.

Figure 9.12 Slime clumps. Left: square a(1,1) of sample Wet 50. Right: square a(1,1) of sample Wet 50.
**Small fractals**

Small fractals are fractal-shaped clusters looking like ice crystals, as figure 9.13 shows. They have sizes ranging from a dozen of nanometers up to hundreds of nanometers. They are narrow, making them hard to see in the figure to the left, but they were easy to find because they were so bright.

![Small fractals](image)

**Figure 9.13** Small fractals. Left: square a(2,2) of sample Wet 50. Right: square a(2,2) of sample Wet 50.

**Exotic objects**

In SSW there were also a couple of Exotic objects. In figure 9.14 are two of those showed, both shaped as a bubble. To the right in figure 9.14 is an object that looks like a halo. Inside the halo was a core made of a shining white substance, which was flat. Around it was also some small particle-looking objects that were smaller than 100 nm. The halo-object has a diameter of 1 \( \mu \)m in the core and 4 \( \mu \)m as a bubble.

To the left in figure 9.14 is another bubble-shaped object, but this one lacks the shining white core. Instead, it has a grey surface that covers the whole bubble. It also is equipped with particles that are in the same size range as the ones which were found in the halo-object. This bubble shaped object has a diameter of 4 \( \mu \)m.

![Exotic objects](image)

**Figure 9.14** Halo-object and Bubble. Left: square a(6,6) of sample Wet 50. Right: square a(1,1) of sample Wet 50.
9.1.3 Open Lead (OL)
The samples from the open leads showed fewer numbers of particles than the samples from SML. On the other hand, the particles that occurred were larger and more complex. Nanoparticles could also be found, but they occurred in groups with fewer members. Overall has the open lead sample has less diversity of objects; Mucus, Strings or Shimmer does not occur at all. Instead, there are some fragile objects that can crumble or vaporize when they are affected by the electron beam.

Nanoparticles
In the OL samples Nanoparticles were found and they seldom came in swarms, as they did in the SML samples. They occurred instead often in pairs, as shown in figure 9.15. Overall, they were one of the most common particles founded in the OL samples. Their sizes reach from about 100 nm to smaller sizes, which make them difficult to count.

Figure 9.15 Nanoparticles. Left: square a(2,2) of sample OL 15. Right: square a(2,2) of sample OL 15.
Assemblies
Assemblies are particles that may have assembled with others. To the left in the figure 9.16, is it like a form of a development circle. The smaller particles clump together, creating larger particles (compare with figure 9.16). The sizes of these particles range from about 0.1 μm up to 10 μm. They occur often in the open lead samples; after nanoparticles Assemblies are the most common particle-type.

Figure 9.16 Assemblies. Left: square a(4,4) of sample OL 15. Right: square a(4,4) of sample OL 15.

Small clusters
Small clusters are objects that are flat and shaped very jagged, in a “fractal”-sense of a way (as shown in figure 9.17). They are ranging from 10 nm and up to a couple of hundreds nanometers. They have perhaps also been assembled into larger objects; two small objects that attach with each other and create one larger object.

Figure 9.17 Small clusters. Left: square a(7,7) of sample OL 15. Right: square a(7,7) of sample OL 15.
Fragile gel

Fragile gel is a category of objects that differs in one sense much from other categories: it breaks when it gets affected by the electron beam. Therefore it was hard to take a picture of them, since it breaks, or perhaps they even vaporized. Before they are photographed, they look like a flat and small pile of white paste. They were not so common, just a handful Fragile gel were discovered. They have a circular shape and are bigger than 100 nm, but smaller than 1 μm in diameter. Fragile gels are shown in figure 9.18.

![Fragile gel](image1)

**Figure 9.18** Fragile gel. Left: square a(4,4) of sample OL 15. Right: square a(3,3) of sample OL 15.

Exotic objects

Worth mentioning is also the discovery of two very specific objects, which only occurred one time each. To the left of figure 9.18, is a worm-like object. It has the size of about 2 μm and is thickest at the middle. The object in the right of figure 9.18 got the name Dashed surface and similar to Fragile gel, it vaporized when the electron beam was directed towards it. Nevertheless, in this case, small strings were left behind after the photo was taken. Dashed surface has a diameter of about 0.7 μm.

![Exotic objects](image2)

**Figure 9.18** Worm-like object and Dashed surface. Left: square a(1,1) of sample OL 15. Right: square c(4,4) of sample OL 15.
9.2 What are their size distributions?

Because of lack of time it was not possible to calculate the size distribution of the particles in any other way than to estimate how often a particle type occurred compared to another. However, the figures 9.19 and 9.20 show how the different particle types would fit in the Aitken and accommodation modes.

![Image of size distributions]

**Figure 9.19** Expected size distributions of SML and SSW samples.

From the upper left corner, going to the right and then down to the left in a zigzag pattern are: Nanoparticles, Small grains, Shimmer, Exotic particles, Fractals and Slime clumps. The figure was inspired by Gao (2012).

What figure 9.19 shows is that no particle in Aitken or Coarse mode was found. Aitken particles could have been found, for instance, if a microscope with better resolution was used. Coarse particles were not found at all. Some particles were a bit larger than the limit of 1 μm, but it was not with so much; therefore, they also were classified as accumulation particles instead.
Figure 9.20 Expected size distribution of the OL samples.

Again, from the upper left corner, going to the right and then down to the left in a zigzag pattern are: Nanoparticles, Exotic particle, Nanoparticles, Assemblies, Assemblies (larger particle), Small clusters and Small clusters. The figure was inspired by Gao (2012).

Figure 9.20 shows that almost no distinct particle from the OL samples was found in Nucleation mode. Again, if we were using a TEM, we could have expected to find some nucleation particles. Overall, the particles were bigger in the OL samples and therefore, also some Coarse particles found, but they were few. However, some particles were a bit larger than the limit of 1 μm, some even reaching 10 μm. The particle in figure 9.20 exemplifies these Coarse particles. It measures 6 μm and the image is taken with x10k magnification.
10. Discussion and conclusions

10.1 Which different particles can be found?

Mucus and Strings
By looking at the figures 9.5 and 9.9, it seems that both Mucus and Strings are made up of the same white-cream substance. Earlier studies from Bigg et al. (Leck & Bigg, 2005) shows a picture (referred as Fig. 5 in Leck and Bigg (2005)) taken on a thin layer of gel from a SML sample collected in the ASCOS expedition of 2001. The gel visually similar to the white-cream substance that can be found on objects categorized into both Mucus and Strings. If all three object types are made of the same material, then Mucus and Strings could consist of what Leck and Bigg (2005) refer as exopolymer secret. In this case, exopolymer would refer to secretion produced by bacteria and microalgae. Then it could also be as Verdugo (2012) describes, that DOC polymers assembles into nanogels, which thereafter can be annealed into microgels (compare with figure 7.4), a possible process that also could link Mucus with String-objects. Mucus could be the substance that Verdugo refers as DOC polymers and Strings could be nanogels.

Mucus and Particles
By comparing pictures in the Strings category (both in SSW and SML), it shows that if fewer amounts of the Mucus-substance are seen in the picture, the more particles there are. Perhaps it could be so that Mucus is the precursor for the particles which can be found in Strings. By some process Mucus might assemble into particles. This idea is reinforced when comparing with images showing larger magnifications of Strings and Nanoparticles (like the figures 9.2, 9.6 and 9.8). The figures show something that can act like a stage between Mucus and Particles: Slime clumps. Photos have been taken on objects, which go under the category Slime clumps, but are located on Strings (like the one to the right in figure 9.8). The strings in question have sometimes in the pictures also some of the Mucus substance left. The process could therefore be something like that mucus assembles into piles of mucus, collecting more and more mucus from its “neighborhood”. These piles grow bigger and start to look like three-dimensional clumps as earlier mentioned Slime clumps. The Slime clumps in its turn assemble more material and consequently, become thicker, leading ultimately to that the Slime clumps go into the stage of Nanoparticles.

Shimmer and Strings
At the same time, the macro-sized objects in the category Strings get more and more transparent, creating “holes” or discontinuities in the Strings, until finally reaching the Shimmer-stage (as viewed in figure 9.4). This conclusion reinforced by the fact that both objects are curved.
Shimmer could therefore be defined as a stage after Strings, made up by the same Mucus-material, but with denser particles creating the transparent surface. By comparing Shimmer and Strings with images taken in previous studies, are they similar to a figure which Orellana et al (2011) refers as low water-soluble organic particle. The low water-soluble organic particles were detected in a sample collected from SML. Orellana et al (2011, p.13615) described it as quantities of colloidal-sized nanogels (<1μm), which annealed into microgels bigger than 3 μm. Shimmer and Strings could then be a structure of nano and microgels.

According to Leck and Bigg (2005) the polymer network that mucus gels are made of, collapses when the ambient pH decreases to 4.5. The pH level in sea water is 8, which means that the air that affects the samples can be important. Also ultraviolet light can split the gel in pieces that cannot reassemble according to Leck and Bigg (2005). This could explain why no mucus, shimmer or strings found in the OL samples.

**Nanoparticles in Shimmer**

The particles which can be found inside Shimmer could be what Verdugo refers as nanoparticles, since they are about 0.1 μm and 10 nm. Therefore they could also be defined as Nanoparticles. When trying to increase the magnification of the particles in Skimmer, it is hard to distinguish the particles; often the picture becomes blurry. This suggests that the particles are flat.

**Nanoparticles and Small grains.**

Considering the size of the particles in the two categories Nanoparticles and Small grains, and comparing their sizes with table 7.1, suggest that they would fit into Aitken mode (Nanoparticles) and accumulation mode (Small grains). By looking through the pictures from the SML-samples, it can be assumed that the result of the particle density would be similar to the one suggested by Gao (2012). It is more particles that are in the ranges 10 nm up to 70 nm, then bigger particles. The smaller particles have smaller volume and therefore, are they harder to find and get a good focus on.

The components of objects from the Assemblies category are similar to the particles that can be found in the category Small grains, which can be found in both SSW and SML. One conclusion could therefore be that Small grains go into the air, where they assemble into larger and larger particles.

**Fractals**

Since the Small fractal objects that were found in SSW have assembled differently than Mucus, in a more fractal-like way, it would be hard to say that they are made up of the same material. Comparing how bright the different objects look on different images, suggest that Fractals and Mucus are made of almost the same material, but some different components in Fractals made a difference in their appearance.
Photos of Fractals show that they have shadows. This might imply that Fractals are “higher” than those from the Mucus category. Comparing with the result from the Open Lead samples, Fractals are similar to Small Clusters. Both objects are fractal-shaped with a relative clear whiteness and are assembled by smaller, similar shaped objects. From this it could be concluded that Small Clusters are made up by the same material as Fractals or even that they are in same category of particles. It could be so that Fractals go into the air by bubble bursting, and transform into Small Clusters. In the earlier study described by Orellana et al, (2011) is also a figure found that shows fractal-shaped objects. Colloidal-sized nanogels tend to present fractal structures in sizes generally <200 nm and always smaller than 1 μm in both SML and cloud samples. (Orellana et al, 2011, p.13615). The definition that Orellana et al (2011) uses also works for those objects who were found in the OL and SSW samples, suggesting that similar objects could be found in the cloud samples which also were collected during ASCOS 2008.

**Fragile gel**

Fragile gel was difficult to take a picture of, since it breaks when you look at it. Perhaps it is made of a material which vaporized when it got affected by an electron beam. In that sense, it differs from the other samples and particles, even the small Mucus did not vaporize when the electron beam was directed towards it. Therefore, some completely different material, compared to the other objects found in the samples, must make up Fragile gel.

Dashed surface in figure 9.18 could also be a Fragile gel, since it became hollow when the electron beam focused at it. Nevertheless, dashed surface did not have the same vaporization style as Fragile gel, instead it consisted of tiny dots and small sticks. In the literature, no similar object could be found, the closets one could be a gathering of bacteria. Because the sticks located inside Dashed surface brings into the mind of bacteria.

Figure 9.18 is similar to the object in figure 4A from Leck and Bigg (2005). Both objects have the same worm-like shape, but the object in figure 9.18 is a bit larger. Since Leck and Bigg suggested that their object could be bacteria, it could be concluded that the object in figure 9.18 of this report could also be bacteria.

**Bubbles**

The exotic objects referred as bubbles were found in SML (figure 9.7) and SSW (figure 9.14), have the same size and contains material that could be described as Mucus. The bubbles could have been vaporized and left the mucus-substance behind, assuming that the bubbles had mucus on its surface from the beginning. These bubbles could therefore work as an example of those bubbles which transports microgels from the sea into the atmosphere by bubble bursting (Leck, 2007). One of the differences between the bubbles that were found in SML and SSW is that the bubbles from SSW also include small particles or grains. Why these grains are found in the bubbles are a bit unclear, maybe they were stuck in the bubble and became stuck in the sample when the bubble vaporized. Perhaps could the assumption that it is a bubble could be wrong from since the beginning.
Maybe it should instead be a smeared out slime clump, or even bacteria or a cell, but this requires future EDS or TEM analysis.

Further more, both Bubbles and Halos have the same circular-shapes and diameters, so they look similar. Even so, the collection of the white-glowing material in the center of Halos suggests that they are different. After comparing the size of the Halos with figure 7.2, it could be bacteria from the sea that is viewed in figure 9.14. The object in figure 9.14 reminds of a cell, perhaps even a eukaryote cell. It would suggest that the “halo” surround the object in figure 9.14 would be the cell's membrane, and the white substance is the nucleus of the cell.

**Crystals**

Further on, Crystals which could be found in figure 9.7 could, due to their edgy and geometric shape, be a salt particle of some kind that is provided from the sea. Comparing figure 9.7 with table 7.1, suggests that these particles could be in the accumulation mode.
10.2 Summarized conclusions

The particles that were found in the SML samples and the SSW samples could be fitted into Aitken mode or accumulation mode. They were also sometimes over 0.1 μm and could therefore act like CCNs. But it was rare that the particles were over 2 μm, making the average size of the particles lower than the average for CCNs according to Seinfeld and Pandis (2006). However, if the conclusions that were described in Nanoparticles and Small grains are correct, then they could go into the air by, for instance, the process of bubble bursting, assemble into larger particles and then take the average size up to 2 μm.

The rest of the objects (for instance Mucus, Strings, Fragile gel) which were found in the SML samples can be expected to come from the biological part of the world (except some of the nano-particles which could have a different origin). If the samples were coated with platinum, the objects could be analyzed further with a TEM (and/or EDS) and it would be possible to detect what substances they consist of. By analyzing the particles like this would give more knowledge of about the objects, and perhaps even a better understanding of their origin and future.

The theory that the team from ASCOS has raised could, as far as we can tell from our research in this master thesis, be true. Similar particles have been found in the water and in the air. It is a good chance that these particles have the same origin and can become CCNs by the processes of assembling, annealing and bubble bursting.
References

Books


Articles


**Internet**


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| C040 |
| I think it was very enjoyable and informative. |
B. Transcribed materials

The sign “#” means that the material have been censored, protecting the informant’s integrity.

A: the app looks like this. I got it for free so… it’s perfect.
Okey, #Name…What was your main assignment for this project?

R: Okey, I joined the project in the beginning of October 2010. After one month I studied at KTH, so I decided to join the project in its very beginning and under the first meeting I said that I would do the structural design of the experiment.

A: Why did you want to join this project? What was your motivation?

R: My motivation during the project was, eh, plain simple, when I came here, after studying in a university in #Country, I thought that only would follow academic courses at KTH would be boring for me. I wanted to do something that is not possible to do in a simple course or in a master course.

A: You wanted a bigger project?

R: Yeah, I wanted to and I also wanted to learn some, I wanted to have an international experience and work in a team, in an international team. And also to do something practical and to see the scale of work in a research project, in a small research project. To and also to see how my education at KTH fits into a research project. (inaudible)

A: Do you feel like your expectations were fulfilled?

R: I think that they were fulfilled. Fully, completely. J

A: So you are happy joining this project?

R: Yes, I am happy but, sort of… It is very good that I thought this way (I went this way) now I think that it was a good decision, I did not regret that I joined the project, that I did a lot of work. But now I’m… I can say that there is nothing, there is not so much I can do, my grades suffered from this, in few courses. Not terrible but it is life. I mean it’s okey. Some of my grades did suffer. Like, I mean, you cannot do two things well in the same time. You should focus on one thing. As I decided in October to peruse this project. I thought that it wouldn’t be wise first to choice to do it and then regret cause I have something else to do. So for me it was this to go for, study in courses and working in project, being active in the project.

A: But, the project was it worth it afterwards?

R: It is worth, because it is an international experience. A research project.

A: Maybe it was more of a personal development?

R: It helped me to develop me professionally and also to develop my interpersonal skills, like communication.

A: What was, like the task that developed you the most? What is to be a team leader?
R: I am sort of, just a second, sorry (mobile phone). Yeah, we should distinguish two faces. Let me tell you about my job and my goals in this project. First of all, let me talk about of the phases in this project. There are mainly 4 phases, 4 phases in this project. According to the type, according to the name of this type of project. It is called Conceive, Design, Implement and Operate, so the project consists of these four parts. In the very early stages you have a goal, you first decide what you want to do, like we had goal. In the very beginning, we had slightly different goal, compared to what we had in the end. First we wanted to build a pressure vessel, an inflatable structure. After a few revisions, after presenting these ideas to the panel, to the euro launch panel, we decided that we had to change it.

A: So they didn’t like it?
R: Yeah, they didn’t like it. So this is the conceive stage. Like what you want, what you need to do, like to collect particles or electric GPS information. I am not really into electronics. I might be wrong in terminology.

A: Its okey, I am not an expert as well.
R: You have different, for example you have these two goals. You collect aerosol particles and to collect GPS data, but you have to different means to do it. In the very beginning we also wanted to build maybe eight probes, or experimental devices. And in the end, we ended up with just two that we are actually going to launch. I mean, in this early stage you have to communicate a lot. You have to brainstorm a lot. You just have to present what you think.

A: What that something new for you or?
R: Yeah, I mean, I knew about this but I did not have experience doing this. So this project presented for me an opportunity to… to… to work it out.

A: To work it out, okey, and train for it?
R: To train for it, I knew about this…. What I knew about this is, I mean, it doesn’t necessarily comes to the project or in theory about the project, how the project should be done. It is related to, for instance, if you want to write an essay you should first brainstormed for your ideas. You have to first bullet point what you think about the specific topic. And then, in the second stage you just cross out what is not relevant or you organize your notebook I guess, this is what we had in the very beginning. So it’s like writing an essay I can say. And then, after you decide on something you need to do something, so if you decided you should do something and see what happens. So we decided to have a concept-design and I made the cut (decided what to change) and then I made pictures of this cut and then we send it to the panel for consideration, to see what they think about it. Again they regretted it and we said okey, then first of all we had a nosecone and then maybe I said that the structure would be to shallow or not big enough or it would not survive, so you should rethink your ideas.

R: I did most of the card, Computing-design-work. I mean, when I say I did most, it doesn’t mean that I did all the work and not talking to other people. It means that we had, usually we had regally meetings, once a week. Each week, we were reviewing the status what was needed to talk about, what needs to be done. If you were facing a problem you just communicated to the other people. So the communication part is very important. And what was…

A: Why was it important?
R: Why it was important? Cause could make decisions, if you discuss it with people, with peers, it’s much easier to get through, to solve these problems that you face. If you are doing it alone, I say or we say that you can get a blind eye. When you work really hard, you try to solve something. You think you did it correctly, but you are blind. You need someone to look at it.

A: So if I understand you correctly, you need someone else to look at your work, so want a new perspective on things?

R: You may think that you are satisfied with what you have, sometimes. But in order to reach perfection, you need to discuss it in a group. And we also, I should say that we were divided into two teams; we can say almost three teams. First team was like project manage team, with one leader #Student2. Secondly like electrical team and then mechanical team. This is no priority in which team that is better or… everyone is equal. The main thing is that we had a project manager, #Student2. He was a very disciplined guy, and he tried, he was all for it. He was always on time, and organizing for us. The most important and most interesting part of this project, you know. There are two things; one can say that you can do it. One can say let’s do this and everyone says, yeah let’s do it. You know, you should have some knowledge how to do it. I, I have small experience to work in a small company.

A: So you didn’t have knowledge before?

R: Yes I had, about CAD but not into space. I never handled this knowledge.

A: But how did you then receive this knowledge?

R: I did receive it in #Country. I had, you know we discussed this with #Supervisor1 and #Supervisor2, our supervisors. One cannot do the RAIN project without prior knowledge, you cannot do it. It is very difficult to learn this in this kind of project. You should have some ideas about how to do it. It is not like you are a white page, you know. That you just come and you don’t know anything. And you want to do RAIN. We were prepared for it. I mean, I started it at Master level, so I knew something about the CAD.

A: So what do you need to…?

R: At least you need to know the software. In this case it was NX Unigraphics

A: Is that like a really special program?

R: It is a regular CAD program, but all the programs they differ in their interface, so you should know this interface at least. There are other things like the drawings, you need to know how to these drawings in CAD program, because they are quite complex. You should specify were need to drill holes, at which angle, at which position and know how to specify this in the drawing. For instance, I was drawing for the rocket cylinder, this took me 10 pages. Before you do this drawing, you must think through the model. You should look at this model and think about were to drill the holes… This didn’t come in a blink of an eye, we had to spend a lot of time on Brainstorming together and when brainstorming something, when we have achieved a certain design, we show it to a panel, they say okey, they approve this. Then maybe #Supervisor1 says “it’s okey, it’s needs to be up again” and #Supervisor2 says “this is not correct, we need to do some calculations”. So we do some calculations, we decides… you decides on everything.

A: Do you think that that is a good method for learning?

R: Yes

A: You do? Why?
R: Ehhm…. I can say why. The good thing here, all compared to course, from what I have taken at KTH. You normally do not touch, or you do not see what you calculating in engineering mechanical.

A: Plain numbers or?

R: Yeah, almost. You work; I mean of course they give you a conception of the thing that you are working with. But when you feel, or you see what happens when you do this or deiced something… You just see that this is not going to work. Or it’s going to work. In the course you do not have a chance to, like visually verify what you have calculated. So you do not feel. If you do not have this… I mean learned some people experience and come to mechanical engineering problem and maybe they did not need, but I thought that I need. And yeah, this is only business design. So there is a lot of interactions, and I don’t know maybe 20 interactions. Before we reach final design, it was 20 iterations. And this is not; each part is not designed separately. So the parts that I designed in assemblies, they are subassemblies.

A: Was it hard for you or?

R: No, this is what I knew how to do. You should have for instance the same type, or try to have the same type of screws everywhere, almost the same type of screws everywhere. Or in a specific subassembly you should try to have the same… It would be stupid to have one screw of this diameter and another screw with another diameter. And

A: Did you try to share your knowledge with the others? How did that occur?

R: Yeah, in the mechanical team. For instance I shared knowledge.

A: How did you do that?

R: For instance, I can say that I talked a next to #Student2 and to #Student3 and I also talked next to RAIN.

A: So you did it standing in front of a white board…?

R: No, just showed it on their computers. So for instance, this is how I shared my knowledge. And I also learned from others, for instance I did not know how to use LayTech, were I did not know anything about it. I learnt it from #Student2. And I did not know Matlab well; #Student2 also contributed to my knowledge.

A: So you really shared knowledge in the group?

R: Yeah, for instance, one… and this CAD program, you cannot learn it yourself. You should at least see how. for instance how I learned. I learnt in a project, in a plant, in a factory, in a design division and there were a person who knew how to use this program well. And I learnt it from him. She was a professional at it and she was an expert at this program.

A: So you were sitting like next to her?

R: Yeah, I was doing my assignments, I was trying to my assignments and if I had a question I just asked him. And this is how everyone who needed to know CAD program learnt it from… If you had a question, okey well you are right, do you know how to do this? Okey, this is done like this. You should click here, it is a problem.

A: Okey, so you can’t learn it like by yourself? Like reading it in a book or something like that?

R: For this special program… How do you say it, there are many of them, but you will not… there are tricks that you should have experienced in this program. Because, if you follow the book, sometimes it is not said in a book, like they why you should put a fatigue. Or you should remove it, I mean you just… It is better to see once then to here 100 times. Or to read somewhere, it is a manual different (big).
A: So it is easier to see someone else to do it and then you…

R: Yeah it is much easier and then you understand how to do it, this sequence or steps. If someone does it.

A: Okey, so it’s like see a tutorial on YouTube or something, it would be similar or?

R: Ehm, yes. Exactly.

A: Your leadership, your leadership skills, was it affected by how #Student2 was a leader?

R: Naaah, I wouldn’t dare to say so. It is so personally. I mean, like, how do you say it? To be honest I wouldn’t dare to say so. I was perceived a leader because I just, I think that my leadership was in this program. Yeah, I did this. I spent a lot of things doing this.

A: Was it your first time to be a leader or? You had been a leader before or?

R: I was a leader before, for some other activities. I don’t know if we… I can say that I had military courses. Within a group of ten people. I had to be a leader, because I was order to be a leader. Yeah and in engineering sense it was my first experience to be a leader like that.

And also…. this is Conceive and Design stage that we are now. In any project of this type, the design stage is… Conceive is when you are trying to understand… you Brainstorm and…

A: …and figure out what you want to do?

R: Yes, then you start to design. The design takes some time, but it better to be done quickly. But it is not always possible, you should… what is important in design stage is to have a concept, a good concept of the structure, what it should do. Like we brainstormed together with #Student2 and everyone. #Student2 did it separately with the mechanical team and the electrical team. (Informant is thinking) We sort of had priorities in each, like functional, requirements sort of speak! We designed for themselves, functional requirements. For instance, the FFU’s should be ejected from the rocket with 6 m/s. From that point of view we had all kind of requirements, designable requirements, functional requirements, operational requirements, environment requirements, different kinds of requirements. So first you, for the design you decides of your goals and also on the requirements of the structure. And from this point, you develop your scheme, the scheme of this structure. And then someone should sketch it and someone would do a cardprint (CAD-print?). So we sketch it together in the team. Like during our general meeting, there were electrical meeting, mechanical meeting and general meetings. And it was very good that we all were in one building, then we collaborate with each other. Because if this kind of huge team, mechanical team and electrical team, if they are far away from each other, there could be misunderstandings, flaws of connections and stuff like that. But these teams should collaborate with each other. So what I am saying is what I have learned.

A: Ok, so was this CDIO perspective integrated in the whole project?

R: Yes. Ahm, people. I mean, in this project it is very important to communicate…

A: …Oh sorry… But have you ever reflected over why CDIO is like a frame for this project? Why you work with it?
R: When you start doing this project, sometimes you don’t know, some people up to know don’t know about this CDIO project, because… I mean I read it, I asked #Supervisor2 about what kind of project. He said, ‘CDIO, look at this website’. I looked at this webpage, MIT, you have seen it? Okey, so it was interesting. And then, of course after 6 months doing this project, I learnt about CDIO and then I understood better. So when people asked. We can say that, if people are aware of this project and of what it should do, so they would do it more constructively. Okey.

A: So you like, explained it for the others?

R: To some peers, not to everyone. I thought, assumed that everyone knew about it. Then our design, we started to do it in February and finished it completely in august. So it took seven months, we planned to be finished in June or in May, because #Student2 went to CDR, Critical-Design –Review in June or July in 2011. But we had not finished fully, completely accurate for these experiment. I did some sacrifice here, I should say, so I sacrificed in my studies, so I did not follow intensely enough. (In another course) I did not get enough knowledge in this course and I did not get a good mark, and I regret about this. And also, I had problems, not because of this project; I had problems in other courses. This sort is not due to this project.

A: But why do you think that you spent more time with this project, then other courses?

R: Cause the scale of this project is much larger and more possibilities, I said that I would do it. It would more worse for me to flop, in bigger, larger project then in a course. I wish I could succeed in both. Even now I cannot solve this problem.

A: What do you think is the big difference to work in a project versus working in a normal course?

R: Oh, okey. First of all, in a normal course it is very dispersed maybe, compared to a dynamic course. Dynamic course has dynamic problems, like RAIN project. In the RAIN, after learning about this CDIO, you understand in which stages you are in right know and what you should do. So you are aware of what you are doing. In a small course, the problems… All the problems in the RAIN project, they are tied to each other. Gradually you come from one stage to another stage. So it is a continuous running. It is not learning like academic work, it is more practical. It is more learning by doing, it is not learning by reading a book. You are reading, you’re calculating, you’re designing, you’re thinking, you’re brainstorming, talking to people. And then, we will come to it… We cannot say that this one is better or this one is a bad course for you. I mean, I am sorry for this but, the difference here is that in a course it is very disperse, in the sense that the problems which you solve, they do not relate to each other. There is no continuous ideology, sort of speak.

A: Is it like there are no correct answers?

R: It is like the problems are different. This week you do this, you are studying this really hard. It was really awkward, I did not like it. In a short course, for instance, one week you are studying a lot of things, and you do homework, then in another week, there is a slightly, we are moving forward to a new topic, which is a bit different from what we studied before, in last week. Then you has to studying again a lot of things, then you have a really difficult homework. So this course also required that you had a really good background.

A: How do you usually study in a normal course? Your study method?

R: At KTH, for instance, I studied following lectures, laboratories, and then read recommended books, or chapters from the books. And do some, regularly we do some problems.
A: Do you think that it is a good method to learn or?
R: It’s important for studying in this method for some time, for a good while I should say. It is good to have this background, it is better to have... It was also something new that I wanted to pursue. Because I didn’t do these kind of projects back at the university. So it was very good for me to do something different. But I suffered from this as well.

A: Okey, did you do any outreach or something like that?
R: Yeah, I participated several times. Not one time, more like 5 times. In the outreach activates. Our first outreach was to Uppsala, to a gymnasium.

A: How did you found this? Was it good or?
R: I found it really good, to speak up. We were speaking in English language.

A: Was it hard or?
R: How do you say it? It was also contributed to our motivation I think.

A: Okey, how come?
R: Because you, you know. When you know that you are going to present something, you want to present it better. And you want to do a better job; you want to be able to present something good. So I think that it contributed to our motivation. And also contributed to speaking. He (another member of the team) had skills about manufacturing. So I learnt something from him.

A: One more question, what are you going to bring with you from this project, what kind of lessons learned and knowledge?
R: I was just watching. So you learn mainly here by just watching. Most of the people cannot do everything. It is very good; I mean a good specialist should know how to do it by hands, in a conceptual, on a computer, how to calculate things by hand. You should know a lot of things.

A: Do you think that you can learn this outside from school? I would rephrase…
R: Yeah, I understand what you are saying. KTH, industry. It depends on the company you work on of course. If you work in a large company, you are not, of course, going to learn everything. Like manufacturing, design, if you chose design, you go for design and sits in the design division. In a large factory, it could be a very large design. In these small scale projects you will have experience on doing almost everything. So in a design division, you are not going to do an outreach. In a small scale project, there are all these misunderstandings and misconceptions. I would like to work in a large company, this is what I think. You can work in a really big company. What it means is that working in a bath company, it’s going to be really good. In a small scale project like this, I mean we are all quite good I think. But, I mean, maybe we are not the best of the best, but we are quite good. And in this quite good group or in a group of quite good members, you learn from each others. Maybe in other companies you are going to be doing specific tasks, and probably you are not going to learn what is going on in another section of this company. And in a small scale project, you have the opportunity of experience everything. It’s like you are going to go through a machine and you are going to learn a lot… It was my idea. I mean I was open to share. You should be open in order to approach this project successfully, or in order to be a useful member or to be an active member you should share your knowledge, share your ideas, be open-minded.

A: Okey, why?
R: Why? I mean, if you are closed up, try to outdo someone you won’t succeed. Because we have a common goal, collective. Collective thinking. You should know that you are doing your part, you should concentrate on your part and it will help everyone. And you should not, how do you say it, if you now if something is done wrongly, you should say this. I mean, or you should not let someone fail. You should be supportable also.

A: Was it you that contacted #Supervisor2, that you needed help or?

R: I think it just went on a meeting, like calculate this. I did maybe some first steps, then #Student2 said okey, we need to redo this. He redid it; we did better or expended the skill or the scope. Then #Supervisor2 came and we revised it…

A: …and discussed it?

R: Yeah, and when we had done this, there was a mistake, a conceptual mistake. Just a contra intuited, the calculation, it was correct. He missed a sign maybe some place, so I…So you see that you get a blind eye, if you do it alone, you get a blind eye. Always. You should do it in a group. It is very good to do everything in a group. Because, you can be revised. It doesn’t mean that, it is not you that did it. Or, I mean, we don’t claim that someone that it is an individual mistake for the project, it is not an individual, it is a collective.

A: How was it to communicate in English?

R: I come from #Country; English is not my native language. It is a different type of learning, I mean, when I was in #Country, I was reading, reading and listening to radio. I did a lot of listening; I studied a lot of words. But here I had to speak up…

A: …so it was a more of practice learning?

R: Practice learning, learning by doing… For me, studying at KTH wouldn’t be as fun without this project. I think it was right choice, even though I missed some courses, some assignments, missed maybe some grades. It’s worth it. I mean, I think if I had A’s in all of my courses, I wouldn’t be as happy. I did a lot of important tasks; I mean I did a lot of important assignments in this project. And of course, they are not so advanced as compared to the course assignments. But there are more valuable for me, I inputted a lot of my energy, and my thinking into this. And I value it more than just a course assignment. But… Yeah, this is my experience. I am glad that I did this project, and that I am at KTH.

A: You are happy?

R: I might not look happy, but in my sole I am happy. It was a really good experience. I am not forced to say this. I liked it! I also liked, during this trips, like to Kiruna, you learned to know people from other countries as well. What the most important thing that you take out from RAIN is that you learn how to work hard, how to communicate with people, you get some practical knowledge how to design, how to conceive, how to manufacture, how to do tests, and what is necessary for this. What time it takes, you understand this timescale. Now I can do this project faster, much faster. Then you know how to do outreach, what it involves. Then you know what you do, you… I said this in the beginning, you start to see what you are studying, what you were studying at KTH, in the practical project like RAIN, you see where it fits. So the engineering mechanics, for instance. The engineering mechanics, master program, it is just a small part, these things that you learn in engineering mechanics courses it is just a small part of this kind of project. You know where it belongs to; it belongs to the design stage, when you do the design. You need to do some calculations. Already in the design stage, you need to do it correctly and functionally. This is what you learn. That is it.

A: All my questions is answered.