JYU DISSERTATIONS 116

Anna-Leena Kähkönen

"Don't You Start Going Solo Here!"

Design for and Analysis of Interdisciplinary Learning Processes for a University Nanoscience Course

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF EDUCATION AND PSYCHOLOGY

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Esitetään Jyväskylän yliopiston kasvatustieteiden ja psykologian tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston vanhassa juhlasalissa S212
syyskuun 13. päivänä 2019 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Education and Psychology of the University of Jyväskylä,
in building Seminarium, old festival hall S212 on September 13, 2019 at 12 o'clock noon.

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2019

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Cover photo: Anna-Leena Kähkönen

This is a printout of the original online publication.
Permanent link to this publication: http://urn.fi/URN:ISBN:978-951-39-7831-0

ISBN 978-951-39-7831-0 (PDF)
URN:ISBN978-951-39-7831-0
ISSN 2489-9003

Jyväskylä University Printing House, Jyväskylä 2019

ABSTRACT

Kähkönen, Anna-Leena
"Don't you start going solo here!" Design for and Analysis of Interdisciplinary Learning Processes for a University Nanoscience Course
Jyväskylä: University of Jyväskylä, 2019, 159 p.
(JYU Dissertations
ISSN 2489-9003; 116)
ISBN 978-951-39-7831-0

The purpose of this thesis was to design a nanoscience course for first-year university students. The designing of the course was realized through design-based research, beginning with the characterization of the context of the course and the most pressing learning goals for the course – the skills a student in nanosciences should have. The characterization involved expert panel interviews, a survey of Finnish opportunities for studying nanosciences, as well as a literature review on interdisciplinary studies.

The chosen outcomes for the course were for students to build their skills of collaboration, belong to a network of nanoscience students, recognize examples of disciplinary cultures, gain experiences in swapping between disciplinary perspectives, and skills for building common ground between concepts and theories. The course design was implemented in 2012 and 2013, with data collected on students' discussions throughout their interdisciplinary group work in the laboratory. The analysis was based on qualitative methodologies; coding the discussions and finding overlap between design features and the mediating processes for each course outcome, as well as a conversation analysis study of the excerpts where disciplines entered the student group discussions.

The design goals of the course were met except for the experiences in swapping between disciplinary perspectives; it was found to be particularly difficult and uncomfortable for students to experience situations demanding this without extra supports from the materials or teachers. The fruitfulness of the laboratory environment in learning collaborative skills was also evidenced in the study. The findings indicate that the first-year students already are apt disciplinary categorizers of one another as well of concepts and methodologies. This key skill received relevant practice with the course materials, showing this intervention to be both effective and relevant.

Keywords: nanoscience education, design-based research, conversation analysis

TIIVISTELMÄ

Kähkönen, Anna-Leena
"Ala ny sooloilemaan siinä!" Poikkitieteellisen oppimiskokonaisuuden suunnittelu ja analyysi yliopiston nanotieteiden kurssilla
Jyväskylä: University of Jyväskylä, 2019, 159 p.
(JYU Dissertations
ISSN 2489-9003; 116)
ISBN 978-951-39-7831-0

Väitöstyön tarkoituksena oli nanotieteiden kurssin suunnittelu ensimmäisen vuoden yliopisto-opiskelijoille. Suunnittelun työtavaksi valikoitui design-tutkimus, jonka alkuvaiheessa tunnistettiin kurssin konteksti ja sen tärkeimmät oppimistavoitteet – taidot, joita opiskelija tarvitsee nanotieteiden opiskelussaan. Tunnistusvaiheessa hyödynnettiin asiantuntijoiden ryhmähaastatteluja, kyselyä nanotieteiden opintoja tarjoaville yliopistoille Suomessa sekä kirjallisuuskatsausta poikkitieteelliseen opiskeluun.

Kurssille valitut oppimistavoitteet olivat oppilaiden yhteistyötaitojen kartuttaminen, nanotieteiden opiskelijoiden verkostoon kuuluminen, oppiaineille ominaisten kulttuuripiirteiden tunnistaminen, oppiaineiden näkökulmien välillä vaihtamiseen totuttautuminen, sekä yhteyksien – "siltojen" – rakentaminen suoraan yhteensovittamattomien käsitteiden ja teorioiden välille. Suunniteltu kurssi toteutettiin vuosina 2012 ja 2013, jolloin aineistoa kerättiin opiskelijoiden keskusteluista pienryhmissä laboratoriotyöskentelyn tilanteissa. Analyysi työssä oli enimmäkseen laadullista, ja sisälsi keskustelujen tyypittelyn sekä yhteyksien etsimisen suunniteltujen toimintojen ja työlle asetettujen tavoitteiden välille – oliko tavoitteiden saavuttamiselle välttämättömiä toimintoja löydettävissä keskusteluista? Tutkimuksessa toteutettiin myös keskusteluanalyysiä soveltava katsaus niihin opiskelijoiden keskusteluihin, joissa oppiaineet olivat eksplisiittisesti esillä.

Kurssin tavoitteet täyttyivät lukuun ottamatta oppiaineiden välillä vaihtamista; osoittautui opiskelijoille erityisen vaikeaksi ja epämukavaksi joutua tilanteisiin, joissa tätä näkökulman vaihtamista vaadittiin ilman tukea materiaalilta tai opettajilta. Laboratorioympäristön hyödyt yhteistyötaitojen kehittämisessä kävivät myös ilmi tutkimusaineistosta. Tulosten perusteella jo ensimmäisen vuoden opiskelijat ovat innokkaita luokittelemaan paitsi toisiaan, myös käsitteitä sekä menetelmiä tiettyihin oppiaineisiin kuuluviksi. Kurssin materiaalit tarjosivat paljon mahdollisuuksia harjoittaa tätä olennaista taitoa ja tekivät oppimiskokonaisuudesta vaikuttavan ja mielekkään.

Avainsanat: nanotieteiden opetus, design-tutkimus, keskusteluanalyysi

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FOREWORD

Findings from this study echo my own journey to become a researcher in education. I started on this path in 2009 with my Physicist lenses firmly in place, wondering what one might do on this side of the lake aside from questionnaires. In addition, I had no idea what anyone else at the department of Teacher Education was doing, no clue of how to tell whether my dappling carried any validity, and in short knew nobody apart from my supervisors.

Slowly things started to become more understandable. I learned from collaborating with fantastic researchers. I owe so very much to my big brothers and sisters in science education research – Antti Laherto, David Sederberg, Suvi Tala and Sari Harmoinen. I gained an all-important step-family from working on the FP7 project IRRESISTIBLE (and its precursor and follow-up applications, even if they went unfunded). I finally started to learn the names of my local colleagues in Education. I did not learn how to stop collaborating with the Science departments. The longing for good ol' times at Ylistö brought much networking into my career, most recently through the LUMA center of Central Finland.

I'm grateful to the Nanoscience education community for seeing a place for my niche expertise and contribution. I'm thrilled to have been invited to work with book chapters as well as to participate in the 2014 Nanoscience and Engineering Education – the Next Steps workshop.

For this thesis, I owe my thanks to professor Janne Ihalainen who trusted me with the whole course design; my co-teachers on SMBP802/NANP1001 Ilari Laajala, Artur Kazmertsuk, Sanna Rauhamäki, Anni Honkimaa, Martin Chilman, and Heini Ijäs; to Sini-Jatta Suonio and Ilari Laajala, who contributed to the research topic through their theses in my supervision; to Pia Petriläinen and Alli Liukkonen, who are like fairy godmothers and whose existence I could not predict based on any experiences in the Physics student laboratory; to Heini Ijäs (double role), Antti Lehtinen, Sami Lehesvuori and Hanna Kronholm for their aid with reliability coding; and to my supervisors Anssi Lindell and Jouni Viiri for their guidance, patience, and putting a stop to this eternity project. I'm grateful to professors Henriette Tolstrup Holmegaard and Kurt Winkelmann as well as Riitta-Leena Metsäpelto for their helpful and insightful comments on the thesis.

To nano students having taken the course – you have taught me tons of chemistry and biology (and some physics) and your appetite for learning has been a big inspiration to me. I've thoroughly enjoyed working with you.

For getting me started on this path, I thank my teachers Antti Savinainen and Rauno Perälä, and my former thesis supervisors Sakari Juutinen, Marcus Rinkiö, and Andreas Johansson.

I'm grateful to my mom and dad, Arja and Seppo, for raising me in an atmosphere where education and research were valued.

To my family, Henri and Sointu: thank you for always supporting me.

Jyväskylä 22.7.2019
Anna-Leena Kähkönen

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1 INTRODUCTION

1.1 Nanoscience education in formation

1.1.1 How to characterize nanoscience

Nanoscience is often defined through the scale of objects that are studied or utilized; for instance

> We define nanoscience as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale (Royal Society & Royal Academy of Engineering 2004, p. vii).

> "Nanoscience" is the emerging science of objects that are intermediate in size between the largest molecules and the smallest structures that can be fabricated by current photolithography; that is, the science of objects with smallest dimensions ranging from a few nanometers to less than 100 nanometers (Whitesides 2005, p. 172).

It is also an interdisciplinary field: the phenomena are simultaneously studied from the viewpoints of physics, chemistry, and/or biology – or toxicology, engineering, and perhaps others. The different viewpoints may be complementary, or in some cases incompatible. These "interdisciplines" have formed at the traditional borders of established disciplines. Sometimes this integrativity and boundary-crossing is used as the fundamental characteristic used in defining nanoscience:

> One of the hallmark features of [nanoscience and technology] is an interdisciplinary viewpoint that integrates traditional subjects such as chemistry, physics, and biology in order to study and to exploit phenomena at the nanoscale. (Jackman et al. 2016, p. 5595).

There are many ways to portray nanoscience. Depending on the choice, a programme to lead students into the exciting field of nanoscience and –technology can take very different perspectives on its subject matter and result in very different selections of materials, teachers, students, and goals.

1.1.2 Development of nanoscience education at the university level

After research in an interdisciplinary field becomes a staple, education follows a few steps afterwards. First offered as courses in methodology or as an introduction, the critical mass is eventually reached. Nanoscience may take the form of a non-compulsory minor subject, or a degree programme. In most places where nanoscience is offered, this is the stage of the transition at the moment – balancing between a course or two based on a single researchers' activity, and a larger entity in its own right. Roco et al (2011) list the movement of nano-education from course supplements to organisations, nanoscience degrees and professional disciplines as a fundamental goal to attain by 2020.

Programmes named with "nano" have indeed been offered, particularly at the master's level, for more than a decade and by several countries, in more than a 100 programmes through Europe already in 2004 (Malsch 2008). Malsch reflects on the situation after the relases of The European Commission Communication "Towards a European strategy for nanotechnology" and the EU Nanotechnology Action Plan, which both promoted needs for a nanoscience education and included funds for creation of research - but also education programmes (2014). The programmes in Finland are reviewed with more precision in section 2.1.

A side note: Pre-college or pre-university education in nanoscience is its own story. While school nanoscience appears widely as a curriculum supplement and has been injected in the national curricula in a few countries such as Taiwan, Australia, or Egypt (in the same order, see Lin et al. 2015, Chen, Lu & Sung 2012, Alford, Calati & Binks 2007, Selim, Al-Tantawi & Al-Zaini 2015), its story is outside the context of this study.

So we're at the formation stage of an educational culture of nanoscience. I want to draw attention to this unestablishedness. Consider a discipline that has a long history. Consider studying chemistry at the university level. Surely there are differences depending on the country and the university in question, but there is a good number of similarities independent of the place of study: there are established laboratory practices to learn, a shared understanding of the big ideas and important topics, a similar way to divide the subject matter (organic chemistry, inorganic chemistry), and a vast amount of handbooks and textbooks for the department to choose from.

Now contrast this with studying nanoscience. Malsch combined data to show that a "specialisation in nanotechnology at postgraduate level after a mono-disciplinary undergraduate education is more common than a specialised nano-education from the undergraduate level" (2014). Depending of whether you study in Sweden or Switzerland, your studies will look very different: either you are studying three separate disciplines, or enrolled in a phenomenon-based integrative study programme, or studying a "regular degree" with an extra course of nano on top. You might be able to complete a Master's degree but not a Bachelor's, the other way around, or pursue nanoscience only at the PhD level (e.g. Zielinska

& Mazurkiewicz 2007). The learning materials could be built from scratch by the teacher for this course, you might be using a textbook, or you get a list of websites with the necessary reading; the contents, range, or important topics in the programme varies from University to another, making it difficult to interpret what your degree means.

For the teachers of nanoscience, it means you could be putting hours and hours into curriculum and learning material development or finding sensible textbooks and supplementing with up-to-date contents, teaching on courses on another department without credit (or co-teaching you course with others not receiving credit). It doesn't help so much to talk to a colleague at another institute, as your curricula are just not built the same way, down to the choice of nanophenomena and the expected expertise built in an area. These are examples that university teachers mentioned as challenges in their nanoscience teaching (Jones, G., Blonder & Kähkönen in press).

Some of the differences are near impossible to remove, because they reflect important, value-based choices. Should nanoscience learning be interdisciplinary from the start or should there be a strong disciplinary basis built at first? Is it in the students' best interest to receive a degree, the contents of which employers cannot easily interpret? Do we buy into

> "Trying to educate an undergraduate broadly in nanotechnology or nanoscience runs the risk of producing a student who knows a little physics, a little chemistry or a little materials science, but would not have mastery in any one area." (Natelson 2014, p. 488)

> "In a time of embattled budgets and overburdened academic resources, it is argued that the interdisciplinary studies programs, with their heavy reliance on team teaching methods, special events, independent study, and relatively low faculty-student ratios are extravagant and cost ineffective." (Benson 1982, p. 46)

or

> "Moreover, when students are thoroughly grounded in a discipline before becoming exposed to interdisciplinary studies, they tend to become indoctrinated into its world view, uncritically accepting its often implicit assumptions." (Newell 1983, p. 4)

Proponents of interdisciplinarity fall into both "camps". Natelson and Benson put high value on interdisciplinary research, and Newell is in favour of teaching interdisciplinary studies alongside disciplines. The goal is the same, but the means are different, and the underlying values (efficiency, openness to ideas, marketability, …) that drive each approach make it impossible to decide which is more successful – successful in fulfilling which goal(s)?

In any regard, this is a good time to build conventions, find unified understanding of the important topics (Sakhnini & Blonder 2015), compare between curricula, share strategies in juggling the interdisciplinary outlook in various situations, and to build models of co-teaching or co-supervising (Lattuca 2001, Science & Justice Research Center (Collaborations Group) 2013, Spelt et al. 2009).

There are also features of interdisciplinarity that require special treatments that do not draw attention (or even may be beneficial) in teaching a single discipline course or content. I'll return to this idea in chapter 2, but maybe two small examples are warranted to set the reader in the right mode: Cognitively, interdisciplinary work requires the ability to use different (theoretical, experimental, conceptual) approaches alongside one another and to bridge across the inconsistencies between these approaches (e.g. Boix-Mansilla 2010). Socially, it requires an ability to work with people *different* from oneself; overcoming the prejudices and the feeling of one's own discipline being the only rigorous, valid or complete way of studying a phenomenon. For example Kekäle (1999) describes a physicist as thinking of all other subjects, with exception of mathematics, as "nothing". This sentiment is occasionally made fun of (see FIGURE 1), which perhaps speaks about its familiarity.

FIGURE 1 A comic strip drawn by a physicist pokes fun at physicists applying physics methodologies (Munroe 2010)

1.1.3 Need for further research

This is an interesting time to experiment within nanoscience education. The conventions are only slowly getting made and spreading. There is a growing network of nanoscience educators who are striving to be a part of this development, co-creating and sharing good practises and other information. There is an audience for studies on learning nanoscience as well as in studying in an interdisciplinary science programme, as nanoscience programmes are available on all continents.

In exploring Bachelor Students' nanoscience studies, this thesis can inform designers of such study programmes or courses as well as offer one viewpoint into the university students' socialization process into their major disciplines, and how the disciplines are present in interactions with students from other disciplines.

1.2 Identifying the problem: A specific need for nanoscience education

1.2.1 The local problem and client

The opportunity to design a new nanoscience course was presented to me by Professor Janne Ihalainen, programme coordinator of the Nanoscience Bachelor studies. His membership in the steering committee of Nanokoulu (Nanoschool) meant he knew I was working with making nanoscience experiments for high school level students. The plan was to use these existing, entry-level materials to design this new course and emphasize the aspect of building a community of nanoscience students.

On the surface, we knew that during the first year, nano students did not have any studies with relation to nanoscience. Within the first weeks of starting their studies, they took part in short, intensive welcome programmes called "Flying start" or "Starting concoction" (depending on the department) with their peers in the department of their chosen major. After this, they attended the first courses in their major subjects in a tight schedule, especially during the fall term.

After completion of the Nanoscience Bachelor's degree, the students would continue onto Nanoscience Lab courses and an overarching Nanoscience lecture course.

What seemed to be missing was socializing with the other nano students before the start of the Master studies, as well as strictly nano content from their Bachelor's degree, aside from the thesis. We asked, could these students explain at home what this nano was that they were studying?

There were a few requirements, then, for this new course:

- To suit Bachelor level students
- To represent nanoscience to students who chose a nanoscience degree, but are uncertain about what it is
- To get nanoscience students to know others studying nanoscience

The requirements could not dictate the content or style of the course entirely, so professor Ihalainen and I decided that I should conduct a study to find out skills the students would need as nanoscientists-to-be, which would already be accessible during their first year.

With my thesis supervisors we agreed that to design the course and to evaluate the design and student learning would be a good topic.

1.2.2 The broad research problem

When the course was being designed in 2011, there was demand for a course to both help nano students from different disciplines to get to know each other in the beginning of their studies, and to guide them towards some first principles of nanoscience.

In undertaking the task of designing a course that should best serve the starting students in nanoscience programme, my initial questions (Q) were:

- Q1. What kinds of skills do students in nanoscience need?
- Q2. How can a laboratory course support the practice of these skills? and
- Q3. What kinds of features of the laboratory session allow the students practice these skills?

Through the course of this thesis and the chosen framework for this study, these research questions will become more specific. I will keep track of the iterated, deepening form of these questions.

1.3 Justification for interdisciplinary orientation of the study

This work is in the intersection of several disciplines. It requires understanding of nanoscience to be able to select relevant contents and to consider skills utilised in doing nanoscience. The praxis of the work is educating students in the nanoscience; thus understanding of learning is central to the work, too. To make informed choices on which disciplines and contributions to invite into the process – and which to rule out – I am following the interdisciplinary research process model (Repko 2012, p. 69).

The starting point in identifying the most relevant disciplines or fields for studying this topic is the collection of potentially relevant disciplines, which carry at least one phenomenon involved in the questions at hand. These are outlined in TABLE 1. Only the disciplines which carried some relevant concepts for this design task are listed in the table.

While physics, chemistry, biology, and mathematics are inherently relevant to the course design, they are not central to the methodology of research in this thesis. They are topical areas of the course. Nevertheless, a working knowledge of these subjects, particularly the recent developments in these fields and their interdiscipline of nanoscience (and/or nanotechnology) is necessary, as well as knowledge educational research in these subjects or their interdiscipline.

TABLE 1 Linking disciplines and their illustrative phenomena (Rick Szostak's classification as reported in Repko 2012) with the design task

Discipline	Phenomenon	Relevance in this study
Biology	Biological taxonomies of species, the nature, interrelationships, evolution of living organisms, health, nutrition, disease and fertility	Some aspects to be learned on the course, particularly the small-scale organisms
Chemistry	The periodic table of chemical elements as building blocks of matter, their composition, properties and reactions	Some aspects to be learned on the course, particularly the building blocks of matter and their properties
Physics	Subatomic particles, the nature of matter and energy and their interactions	Some aspects to be learned on the course, particularly interactions
Mathematics	Logic of numbers, statistics, mathematical modelling, computer simulations	Some aspects to be learned on the course, but less than the other three sciences
Anthropology	The origins of humanity, the dynamics of cultures worldwide	Concept of cultures, cultures of disciplines and research
Psychology	The nature of human behaviour as well as the internal and external factors that affect this behaviour	Psychology of learning, psychology of collaboration
Sociology	The social nature of societies and of human interactions within them	Human interactions formation of a network
History	The people, events and movements of human civilizations past and present	Historical developments in nanoscience education

Anthropology, Psychology and Sociology appear in the list through the human subject experiencing this course, each offering their own window into the problem. Cultures appear at the intersection of Anthropology and Sociology, and appropriate methodologies and methods to take both points of views into account will be looked at in later chapters. In addition to participating in a culture and a social setting, the human subject is in a learning environment in taking this course. Education is the overarching theme for many of the slots in TABLE 1. Curiously, it is not mentioned in Szostak's classification scheme at all (apart from music paired with music education). Education is viewed as an interdiscipline with elements mostly of psychology and sociology in this scheme.

Through this study I will visit the boundaries of psychology and sociology as well as science education. A synthesis of ideas about learning and the research methods available to capture it, and their disciplinary backgrounds, are again examined in Chapters 4 and 6 respectively. History I decide to leave out at this point as a major influence. Some episodes from history will be recounted in describing the context, but the intention is rather to illustrate than to examine or analyse. The application of several disciplines means that this thesis will contain some boundary work in using these methods as well as findings in unison.

1.4 Design-Based Research as a roadmap

1.4.1 Choosing design research as a roadmap for the study

Looking at a division of research functions into five main categories (Plomp & Nieveen 2013, p. 13) it was possible to choose the ones most relevant in this study. The categorization is shown in TABLE 2, with the broad research question split between the functions.

TABLE 2 Research functions and research designs (from Plomp & Nieveen 2013, p. 13-15) and the aspects of this thesis study relevant to each

Research functions	Research designs that can realize this function	Research question contents or other expected contribution
To describe	Survey Case study Ethnography Correlational research	Q1: What skills do students in nanoscience need? Q3 (partial): How do students act in their interdisciplinary environment? What kinds of occasions do they practise the skills in?
To compare	Survey Case study Experiment Correlational research	
To evaluate	Survey Evaluation research	Q3 (partial): Did the learning activities result in practise and in learning of skills?
To explain or predict	Case study Experiment Ethnography	
To design and develop	Action research Design research	Q2 (partial): What kinds of learning activities give nano students possibilities to practise the important skills?

This study is concentrated on the design and development of learning activities, but through the design activity – the in-depth problem analysis as well as the evaluation of the activities - subquestions will produce information also on describing, explaining and evaluating. Some examples could be describing the desirable learning goals, explaining students’ reactions to working in interdisciplinary groups, and evaluating strengths of laboratory worksheets.

Comparing these functions with some research designs in educational research, it could be predicted that while the *big structure* of this thesis will adhere to design research, there will be subquestions that are best answered through designs originating from anthropology or sociology; this thesis will include ethnography, and ethnomethodology (e.g. Conversation Analysis), as well as interviews, and also some quantitative evaluation research through coding and classifying.

Design research here is a particularly suiting choice, given that the goals of the study are closely related to the design of a learning sequence and its related materials, as well as understanding the functions of the parts contributing to this learning sequence. The Design Based Research Collective (2003) view Design research as ”an emerging paradigm for the study of learning in context through the systematic design and study of instructional strategies and tools”. The benefits of the paradigm are crystallized in the word context; all results are intertwined with the practise, the participants and the materials. The collective emphasizes the holistic view of the educational intervention, of the interplay between materials, teachers and learners. Simultaneously this means that the findings will not be clear-cut answers on whether a hypothesis holds; Barab and Squire (2004) characterize the findings of design research as involving “looking at multiple aspects of the design and developing a profile that characterizes the design in practice”.

It is sensible to note here that design research is not a clear-cut methodology set one ascribes to or not. There are many traditions that are close or overlap, such as instructional design (ID), developmental research, or formative research, which share the same goals and often design: to develop an instructional composition – a tool, a lesson, a curriculum - using an iterative process based on analysis and evaluation of the prototype (e.g. McKenney & Van Den Akker 2005, Cobb et al. 2003, van den Akker 2007).

Why not action research? Action research is suited for local development, which sounds like a good option for a process of developing a course that would be, for the most part, also taught by the designer. Many of the features indeed are shared: the results feeding into theory, and the development, the researcher as participant (Reason & Bradbury 2001). In it’s premises action research is collaborative, deeply ingrained in the actions of the participants – all participants contributing to the research together, not making a division between subjects and conductors of the study (ibid. p. 39). This is removed from the objective of the design task here; while it would be possible to collaboratively explore the best ways to learn the nanoscience practises, students and teachers building the “solution” together, it is not the course taken here. It puts a limit to the students’ voice being heard in the designed course materials; on the other hand it enables the researcher to make design choices that are research-based but possibly not in the students’ comfort zone – such as one of the course goals suggests, the students should actively get to know other students, while a good portion of the students would prefer to work alone or with just one or two familiar partners (as illustrated by the learning styles indices - seeLitzinger et al. 2007). Also, the course and its materials should come to exist and continue to exist without the researcher's presence. The two-fold goals of design research in both refining the design object as well as development of theory are important for the thesis.

As the design research is oriented on the design process and the real-world application of the design, it warrants for a pragmatist approach on the collection and subsequently analysis of of data. The pragmatist worldview allows for combining qualitative and quantitative methods on the data in answering the research problem (e.g. to evaluate of the design product); it could include both subjective/biased and objective/unbiased perspectives, and also mixed qualitative and quantitative data (Plano Clark & Creswell 2007, p. 24).

1.4.2 The design cycle

While several models for realization of a design-based research project are available, they share the same rough structure illustrated in FIGURE 2. Among Instructional Design (ID), the precursor to Design-Based Research, the ADDIE model often is used to describe the major processes in the generic design process: Analysis – Design – Development – Implementation – Evaluation (Molenda 2003).

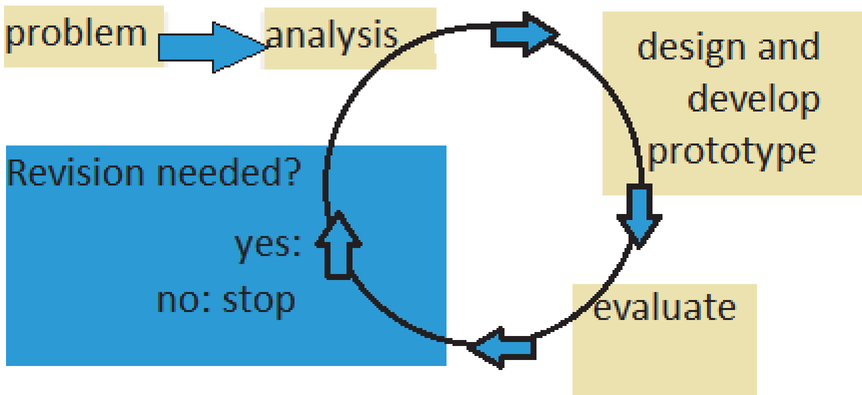

FIGURE 2 Iterations of systematic design cycles (adapted from Plomp & Nieveen 2013, p. 17)

Some models of learning design to consider for curriculum design are the ILD (Integrative Learning Design) framework (Bannan-Ritland 2003) and the CASCADE (Computer Assisted Curriculum Analysis, Design and Evaluation) program (McKenney & Van Den Akker 2005). The ILD is specific but broad: the model includes veins of publication and dissemination as well as a large-scale adaptation of the design. The CASCADE model is relevant as it is meant for use in curriculum design, and it puts a focus on the rationale for development of a course. Aspects of the CASCADE model can be learned from the descriptive research articles, but alas the programme is no longer available. The Conjecture Mapping model (Sandoval 2004) treated the design characteristics and their internal relations very visibly, drawing the connections between the theory basis of a designed object or teaching method, the expected actions, and the expected learning outcomes.

After a review of possible models for design research, the Conjecture Mapping model as a design aide (Sandoval 2004) seemed to be a best fit for this purpose. A conjecture map is drafted in chapter 5.1. At this point of the design process, the following steps are to chart the context and settings (in chapter 2) in which this course is to be created, and to analyse the needs of the students – reviewing from literature what doing nanoscience research or interdisciplinary research requires, and contextualizing it through the stories of local nanoscience researchers and older students (in chapter 3). After this, I overview some relevant views about learning (Chapter 4) so that the concept map has a theoretical starting point: how do we believe the relevant skills in this context are learned?

A house-building analogy of the synthesized model for the design research around development of a first-year nanoscience course is shown in FIGURE 3.

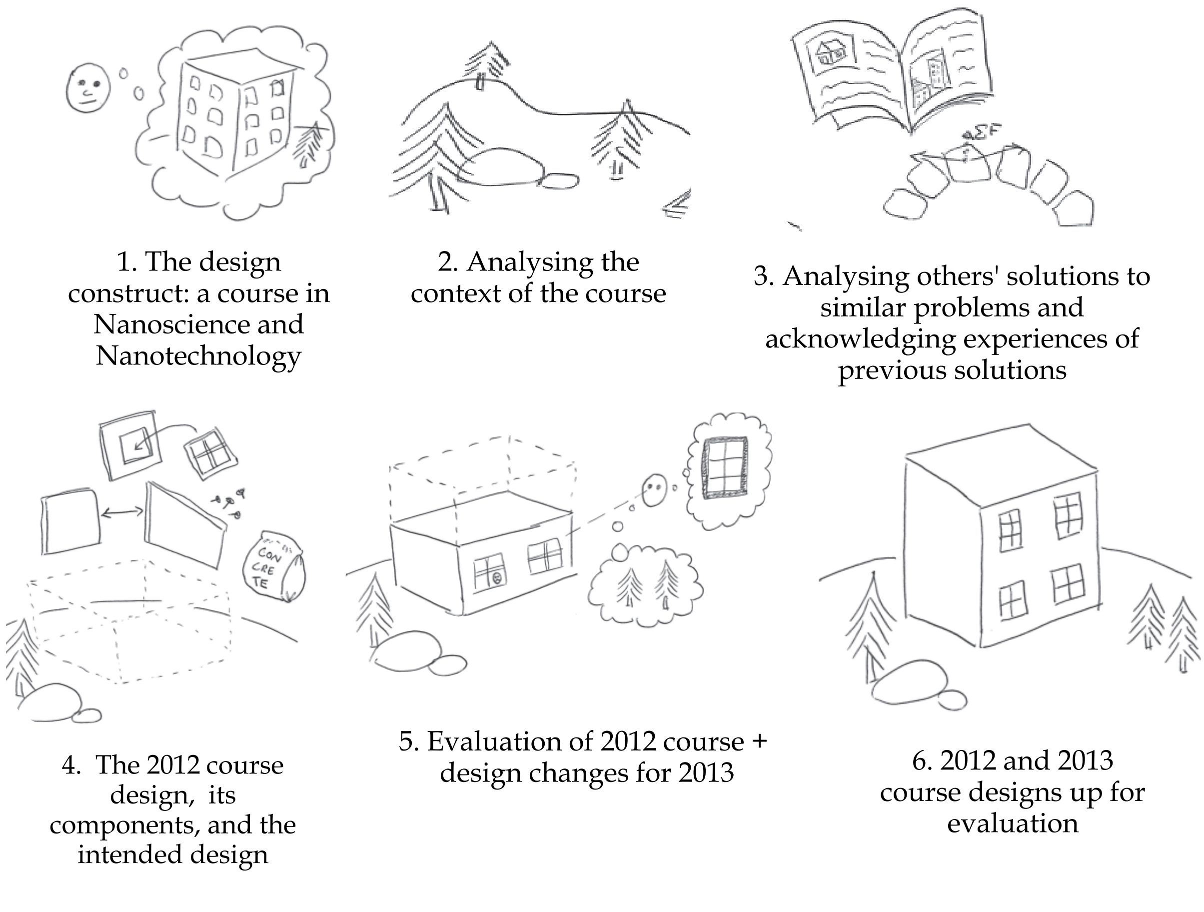

FIGURE 3 An analogy of house building for the design process of construing a course in nanoscience and –technology

Within this thesis I am most interested in exploring the actions and practises of students within the frame of the designed course, i.e. the link between the designed embodiments and how they translate into the intended action – rather than the fulfilment of particular learning goals. That means that the evaluation of the students' learning of nanotechnological concepts, for example, is not in the scope of this thesis, while it may be the topic of further studies on this course data. Students fulfilments of the learning goals has naturally been evaluated on giving each students’ course mark and feedback already; evaluation of the course in how well it helps students fulfill these goals is another matter.

2 UNDERSTANDING THE CONTEXT: INTERDISCIPLINARY NANOSCIENCE AND -TECHNOLOGY IN FINLAND AND IN JYVÄSKYLÄ

The important outcome of this thesis work is the tested and improved course material and structure for an introductory course in nanoscience. Parts of this material should be transferable to other contexts, yet the overall design was tailored to the particular requirements of the place of implementation – the Nanoscience bachelor study programme at University of Jyväskylä, Finland.

The chapter deals with the context analysis in the Design research framework. The purpose is to understand the building blocks of the course – the local base it will exist in (i.e. the Finnish and the Jyväskylä settings for studying nanoscience). I should be aware of the other solutions to this problem – i.e. how other Finnish universities have undertaken teaching in nanoscience.

The research questions for this chapter are about the context of the course:

- How are nanoscience study opportunities elsewhere in Finland? and
- How are nanoscience studies organized in Jyväskylä?

2.1 Existing solutions: nanoscience studies elsewhere in Finland

2.1.1 Informants and data collection

Within Finland, there are not many options if one wants to focus on nanoscience at University level. Most universities focus on the traditional disciplines or engineering. Some are ruled out as they do not offer studies in Science subjects (University of Lapland, Hanken School of Economics, Uniarts Helsinki), or the relevant Faculty is focused on large-scale technology (e.g. University of Vaasa Department of Electrical Engineering and Energy Technology). Universities of Applied Sciences were not considered as part of this fieldmap; this study focused on nanoscience researcher education. Further, no nanotechnology related search terms returned hits on the websites of Universities of applied sciences, and only hopes for developments in this sector were mentioned in the Nanovision 2020 document charting the current and envisioned status of nanotechnology research and education in Finland (Academy of Finland 2011).

The other universities were approached in fall of 2014. The author sent e-mails to staff members that were connected to nanoscience activities in the university Staff Directories. When such persons were not easy to find, the department secretaries were asked to forward the e-mails to a person who would know about the topic. The recipients were asked whether their universities offered a degree programme or a major subject in nanoscience or –technology, whether they had courses with nanoscience contents, and if the courses are limited to members of a single discipline. Along with some discussions on what was considered nanoscience, and directions to contact someone from another faculty, the author received helpful answers from all of these universities. In some cases, the University web sites could also help confirm whether single courses were offered.

2.1.2 Results: Finnish universities' reported nano education opportunities

Worldwide NST degrees starting at Bachelor's level have started at dozens of universities across Europe and North America alone (Malsch 2014). At Master's level, there are plenty of opportunities in Europe, available to a Finnish student via Erasmus or other programmes. This survey was to chart the opportunities to study nanosciences within Finland.

The results of this field mapping are shown in TABLE 3. The mode response was that there are some courses offered, that the topics surface within many other courses that aren't specifically dedicated for nanoscience, and that it's not offered as a degree programme for either Bachelor's or Masters. After a quick update in 2019, it appears that out of the universities below, Aalto university has began offering a Master's degree programme in "Electronics and Nanotechnology" (Aalto University 2019).

The respondents also gave some background in their answers about the degree programme possibility. For some, the attitude was positive ("We've been talking in the Faculty about having a nanoscience major, for two years now") and some, negative ("We highlight the phenomena as parts of physics and chemistry, but not at a programme level, since it might not carry its novelty value into the future") towards establishment of a programme. Both answers show that the faculties are not springing to make quick moves to accommodate something that could be short-lived. Building up a programme is careful and considerate work, and with little examples from the other universities to build upon, it is a venture that requires a lot of effort. This positions Jyväskylä's programme as a bold move in the national scale.

TABLE 3 Nanoscience and -technology (NST) studies offered at Finnish universities with science / engineering departments in 2014

University	Offers degree programme in NST	Offers course(s) in NST	Programme or course(s) open to different disciplines
Aalto University	no[1]	yes	yes
Tampere University of Technology[2]	no[3]	yes	yes
University of Tampere[2]	no	no	-
University of Turku	no	yes	yes
Åbo Akademi University	no	yes	-
University of Oulu	no	yes	-
University of Eastern Finland (Kuopio and Joensuu)	no	yes	no
Lappeenranta University of Technology	no	yes	no

The nano-related courses that were offered in most universities (see TABLE 3) are much easier to set up than a programme. They involve only a handful of personnel and can start from the enthusiasm of a single actor. Many had, according to the respondents, been taught for 5-10 years and were established as stable elements in degree studies. Some respondents named a few courses that their universities offered; TABLE 4 is not a comprehensive list, but gives a good idea of the variety of topics that are explored in bachelor or master level studies.

TABLE 4 Examples of nanoscience and –technology (NST) related courses offered at Finnish universities in 2014

Discipline-based frame	Topic-based frame
Nanophysics (x2)	Introduction to applications of nanostructures
Nanochemistry	Micro- and nanophotonics
	Nanoparticle technology
	Nanoparticles in energy technology
	Colloidal sol-gel processing of nanomaterials
	Introduction to nano and radio sciences

TABLE 4 was also interesting in terms of framing the courses by choices in naming. They ranged from seemingly general coverage (“Introduction to …”) to very specific (“Colloidal sol-gel processing of …”). The other frame is whether the course is appointed to a specific discipline. The contents of the course may not

1 Aalto University currently (2019) offers a Master’s degree course in Electronics and Nanotechnology.
2 The Tampere University of Technology and University of Tampere fused in 2019 to become The Tampere Universities.
3 Tampere University of Technology offered an international master’s programme ‘Science and Bioengineering’, where one of the Majors was Nanotechnology. The programme ended in 2016 and student intake in 2014.

agree with the frame conveyed by the naming convention ("Nanochemistry" might very well tie in materials and methodologies from other disciplines), but it works to set a mood and expectations.

Lastly, the respondents assured the author of the coverage of nano topics within other relevant courses, where they were "hiding", such as nanofiltering or nanofibers as topics within the course "Separation techniques". The history of discussing the nanoscale in courses seemed to go far, with mentions of nanostructures in optics being taught since 1995.

Not all respondents commented upon the participation of students from different disciplines. Some identified the exact majors from which students had the option to study this course. While some answers are lacking, they are enough to show that the courses may be organized specifically for one discipline or as open for students from different fields – although in all answers, the fields were closely related. All were within science and engineering, e.g. "chemists, but also some physicists" or "students are from solid state physics, material science, or the physics section of medical technology."

2.2 Nanoscience opportunities at University of Jyväskylä

2.2.1 Intensive welcome programmes in Jyväskylä

These programmes were developed during the last 20 years to give the new students a glimpse at the science that was being done in their home department and to spend time bonding with a peer group and a tutor and getting at least somewhat familiar with a chosen cast of faculty. Nanoscience was one of the topics the student groups briefly explored during the programme weeks. Duration of the programmes varies somewhat; the first day is the first of September, and depending on the day of the week, the programme runs for something between 6-10 days until the regular studies start on a Monday.

The results of these programmes had been positive in terms of students enjoying the intensive schedule, settling into their departments, being exposed to staff members, finding peers, and getting a study routine at the start of their University studies (in Physics: Halkosaari 2006, 2004, in Chemistry: Tulonen 2016, Valtonen 2008). There is evidence that the student dropout rate has fallen since the adaptation of the Flying Start (Halkosaari 2006, Tulonen 2016).

The nanoscience students experience the welcome programmes in their respective departments. In the year before designing this course, a designated Nanoscience day was organized. There all nanostudents starting that year met and toured the laboratories and completed a nanoscience hands-on experiment, which was hosted by me. In the following years this Nanoscience day was no longer put together, for several reasons:

- there were fewer days in the Flying Start or Starting Concoction programmes because of the starting day, September 1, position in the calendar week

- some students choosing nanoscience were choosing it only after the Flying Start programmes, during another application round, and,
- the new first-year nanoscience course was seen to fulfill most goals of this day.

No study about the effects of Nanoscience day was carried out, however having a dedicated session at the very beginning of the studies starting would be intriguing to try out again.

2.2.2 Curriculum overview: Nano studies in physics, chemistry, and cell and molecular biology

2.2.2.1 Nanoscience Bachelor's programme in Jyväskylä

The Nanoscience Bachelor's (NAB) programme began in 2007. Students enroll in the program with one subject as a major and two others as minors. There is little room for other elective studies; depending on the major subject, the amount of credit points reserved for other subjects is different, ranging from 11 to 26 ECTS (Faculty of Mathematics and Science 2018a).

The NAB curricula are different from other students' taking the same major subject. They take less compulsory courses in their major than their peers, and their minor studies are outlined a little differently from a "generic" minor in the subject. This is to help students focus on the areas of knowledge most relevant to dealing with nano world, without bloating the curriculum unnecessarily. Tension comes from trying to make the major and minor subjects fulfill the requirements for a standard major or minor in the subject, should the student cease his/her studies in the nano vein after or during the Bachelor phase (Heikkilä 2014, p. 71).

The interdisciplinary contents of the NAB programme were not many in 2012; it sometimes included one lab work course of 6 ETCS credits. As a former nanoscience labwork course that had initially been created as a first-year course, it had become more demanding in course of time, as the course responsibilities were delegated to varying members of different research groups. Many students ended up taking this course in their Master studies, resulting in no shared nanoscience courses during the Bachelor phase.

Currently, in 2019, the NAB programme offers both the NANP1001 Nanoscience and –technology (2 ECTS) for first-year students and the lab course NANA2001 Molecular interactions (6 ECTS), suggested in the third year (Faculty of Mathematics and Science 2018a). And of course the Bachelor's thesis (9 ECTS), which often is interdisciplinary in nature. This totals 17 ECTS credits, nearly 10 % of the programme (180 ECTS).

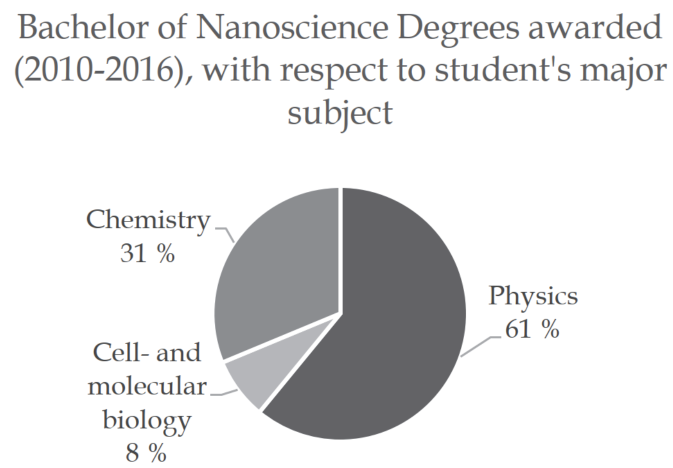

FIGURE 4 Bachelor of Nanoscience degrees awarded in years 2010-2016, classified per the major subject of the student

The first NAB students graduated as Bachelors by 2011, and by the end of 2016, there was a total of 64 Bachelors from the NAB. For division of the degrees per granting departments, see FIGURE 4. The student intake has been 24 on average per year, up until 2015. Of the NAB students, 34 so far have completed a Master's degree, and 9 are pursuing a doctoral degree. (M. Korhonen, personal communication, March 31, 2017)

The intake numbers and completion of degrees are nowhere near the same; on average, 47% of the students having begun studies in 2012 or earlier have completed their Bachelor's degree. This is roughly similar to other study programmes in the Faculty of Mathematics and Science.

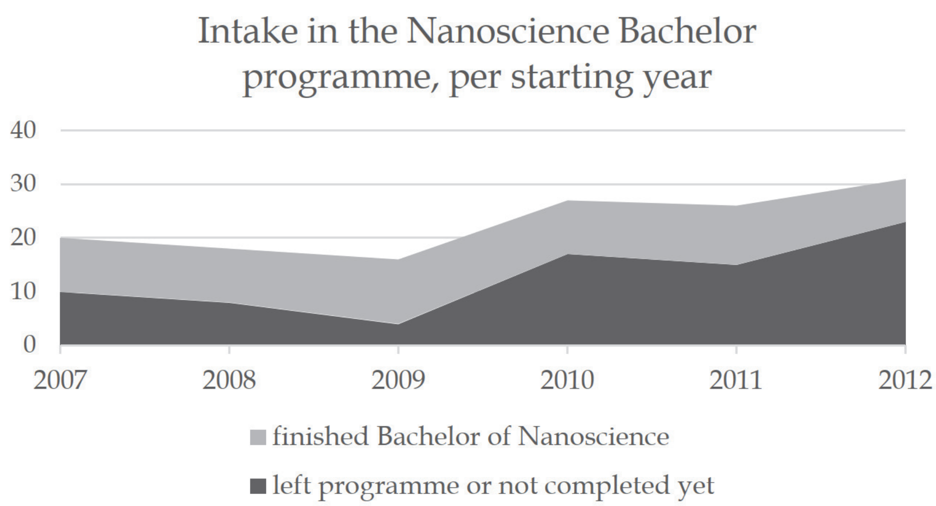

FIGURE 5 Portion of the students completing their degree by 2016, per starting year. Figure shows the total number of students having accepted a study position, and in light grey, the number of students from each starting year that have finished a Bachelor of Nanoscience degree. Starting in year 2012 gives 4 years to complete a Bachelor's degree, and reflects a likely number of total graduates from this cohort.

Curiously, in 2016, the total number of students accepting a student position was only 11. (M. Korhonen, personal communication, 31. March 2017). The drop in numbers likely reflects the changes in Finnish higher education for 2016: the Universities are required to reserve a quota for first-time applicants only (Studyinfo 2017) and the regulations concerning a fixed amount of grant months towards any university degree studies (Kela 2016), making it more difficult to pursue a different degree later.

2.2.2.2 Nanoscience Master's in Jyväskylä

The Nanoscience Master's was the first nano programme offered at the University of Jyväskylä. It started out in 2003 as an international study programme for talented students with bachelor-level background in science. Many of the students taking the programme are international; the statistics for 2013 report 17 different nationalities amongst the 50 finished degrees (Heikkilä 2014, pp. 69-70).

The Master's programme today includes studies separately in physics, chemistry, and cell and molecular biology, as well as interdisciplinary contents such as a lecture course "Fundamentals of Nanosciences" as well as a laboratory course in imaging, a computational course in nanosciences, and seminar courses (Faculty of Mathematics and Science 2018b). The master's thesis in the Nanoscience Master's is of an interdisciplinary topic. The interdisciplinary contents total at 46 ECTS credits, making up already near 40% of the 120 ECTS programme.

2.2.2.3 The National Graduate School in Nanosciences (2006-2015)

The National graduate school in Nanosciences (NGS-NANO) was started in 2006 (Heikkilä 2014, p. 70). The programme was coordinated by University of Jyväskylä, and students who pursued nanoscience PhDs at any Finnish university could apply. The programme had annual student meetings and offered either affiliation or affiliation with funding to students. The students were required to take interdisciplinary courses or courses in several disciplines, ensuring a multidisciplinary stance, and choose a thesis topic that required knowledge of two or more disciplines. They were also required to have supervisors from more than one discipline (Nanoscience Center 2015, 2011).

With the change in funding schemes of the Finnish Academy of Sciences, the national graduate schools were gradually run down and ended in 2015. This was the fate of NGS-NANO, too. The graduate students in nanosciences today enroll and study within university-based graduate schools, without National governance.

2.3 Adjusting to the local realities in Finland and in Jyväskylä

Within the context of Finland, Jyväskylä's decision to accommodate a nanoscience major throughout the studies stands out. Seeing how the programme is constructed – using disciplinary courses from each of the contributing disciplines as the bulk of the programme, with supplements of interdisciplinarity constituting a very small portion of the studies altogether, the end result is not necessarily very different from how a student could organise her studies at another one of the universities offering single interdisciplinary courses. The difference is minimal, at least in comparison to a programme built with interdisciplinary courses and supplements of discipline-specific learning. Nevertheless, structuring the studies into a programme with a continuously better-recognized name, as part of the degree, means that University of Jyväskylä is making it possible for the student to advertise her expertise in nanosciences from an early level on.

The offering of nanoscience education – in varying amounts - at all Finnish universities that have a Faculty of Science or Engineering means that the design process, choices, and particularly results of this study will have a possible audience in all of these universities. One of the goals of this study altogether should be to reflect on the choices and results at University of Jyväskylä and to single out information that transfers to other locations, if not to other contexts.

The Nanoscience Bachelor's programme at University of Jyväskylä has initially been very stable in its students continuing in the programme and receiving a degree (see FIGURE 5 Portion of the students completing their degree by 2016, per starting year. Figure shows the total number of students having accepted a study position, and in light grey, the number of students from each starting year that have finished a Bachelor of Nanoscience degree. Starting in year 2012 gives 4 years to complete a Bachelor's degree, and reflects a likely number of total graduates from this cohort.FIGURE 5), but the later cohorts have higher rates of dropping out or changing into another programme within or outside of the University. This may reflect on the situation where students were not taking any combined nanoscience courses initially or their difficulties in structuring their studies otherwise, making their Bachelor studies phase simply last longer.

The status of this first year course is to give an initial outlook to the field as well as to bind the students together, helping them advance through their studies and into the Nanoscience Master programme. Seeing that the further nano-specific courses offered are about imaging and molecular interactions (computational studies have appeared later), the introductory course could offer an introduction into both of these topics. This way it will make a seamless fit into the continuum of interdisciplinary nano studies offered through the programmes from Bachelor to Master level.

The getting to know one another goal of the course is also relevant, particularly after the dropping of the Nanoscience Day at the beginning of the study year. The students are expected to not know nano students from the other two disciplines on entering this course, so this is a good insertion point in the whole programme to start familiarizing with the local nano community.

3 MAPPING THE ESSENTIAL SKILLS TO BE LEARNED ON A NANOSCIENCE COURSE

Why pay attention so much to features of a niche of science? To be able to design the learning sequence in a way that really targets the necessary skills, I need to look deeper than picking examples from existing learning materials in physics, chemistry and biology. The needs of studying in an interdisciplinary context will be different cognitively – having to create common ground between conflicting theories or concepts – as well as socially – having to work in a multidisciplinary environment or swapping between environments. How can I concretize those features and needs to this problem of offering a first small introduction into interdisciplinary study and research, so that it reflects on the nature of nanoscience as well as helps students gain skills they will need in doing nanoscience?

For a detailed treatise of the interdisciplinary nature of nanoscience, see Kähkönen et al. (2016). Here, I will introduce interdisciplinarity and training for interdisciplinarity in a compact and general manner. The skills relevant to working in interdisciplinary settings and to studying an interdisciplinary topic are thus explored with also other contexts than nanoscience, as there are some universals in interdisciplinary work – those will be covered in this chapter.

Getting a local eye on this design task was also an important part of the needs analysis phase in Design Research. Students' experiences could inform me about the needs master's and doctoral students had or saw in earlier parts of their studies. It was also useful to have a longer perspective in how student years have shaped a scientist's skillset, or if they were now, in their mentor or teacher roles, seeing their students struggle with some ideas in particular. These perspectives were sought by small group interviews with local nanoscience students and researchers.

The research questions for this section are

- What skills or experiences are recognized as relevant to students in (other) interdisciplinary fields in general or in nanoscience in literature?
- What skills or experiences are held in value by local nanoscience researchers or students?

3.1 Studies and Work in Interdisciplinary Research Settings

Guidebooks available to students taking interdisciplinary majors start with the assumption that such study programmes have at least some shared features, regardless of the participant disciplines – you can acquire a book that

> "describes how to actually do interdisciplinary research using processes and techniques of demonstrated utility whether one is working in the natural sciences, the social sciences, the humanities, or the applied fields" (Repko 2012, p. xxiv)

or one that will accompany you as you may

> "reflect on your life and goals, reflect on your worldviews, identify your skills, assess your strengths and weaknesses, understand the nature of disciplinary knowledge, fully understand the disciplines from which you will draw knowledge and insights" (Augsburg 2006, p. 8).

This kind of a guide for work between any disciplines will be a good starting point. The finer distinctions, such as epistemic features of a research tradition within a discipline or the culture in a certain field are details that could be built on top of the general understanding. The philosophy of interdisciplinary science focuses more on interpreting features of interdisciplinary science, but can provide ideas and perspectives for realizing relevant skills (Mäki 2016).

This literature review will go through some recommendations for interdisciplinary studies, some based on findings on existing programmes, some on more varied ways of organizing studies such as integrative studies or liberal studies programmes, where the target is to gain a broad education and outlook, with considerable freedom for the student in shaping the programme e.g. through choices of minor subjects (Augsburg 2006, p. 20).

This review is not focused on disciplinary background knowledge and perhaps is removed from knowledge requirements altogether; the focus here is on the less tangible skills and awarenesses that are central to interdisciplinary work. For a mapping of competencies and knowledge requirements for a nanotechnology job from a qualification point of view I refer to the European Centre for the Development of Vocational Training report on the matter (Abicht, Freikamp & Schumann 2006).

3.1.1 Recommendation: Realizing the power of enculturation

Researchers interested in promoting interdisciplinarity in the academia have highlighted the importance of interpersonal skills and tendencies in interdisciplinary research. They mention personal qualities such as respect, and openness (Stokols 2014, Repko 2012, Spelt et al. 2009).

On the other hand, the interpersonal skills are amongst the learning goals for interdisciplinary education. Interactional expertise has a large significance in interdisciplinary work. It can mean composing and upholding networks (Kähkönen et al. 2016, p. 53, Stokols 2014) or taking an active role in facilitating co-operation between different areas of work (Tala 2015). Richter and Paretti (2009) dub the inability to see connections between a new context and one's familiar disciplinary setting, "disciplinary egocentrism". It is at the heart of the inability to value the multiple perspectives on solving a particular problem. From interviews with an engineering student cohort subjected to an interdisciplinary course, they summarize,

> "When students fail to see connections between their own discipline and an interdisciplinary subject or problem, they limit their ability to incorporate new ideas and practices into their own work. They also limit their ability to contribute to larger interdisciplinary problems, believing that their work has nothing to do with those problems. "(Richter & Paretti 2009)

They give a short list of suggestions for the teacher of an interdisciplinary course to help students become aware of this phenomenon and to combat it:

- Creating discussion in the classroom by asking students to state explicitly how their discipline can contribute to a specific problem.
- Asking students to reflect on questions such as "what does it mean to be a member/practitioner of my discipline?" and then share those answers with members of different disciplines.
- Creating dialogue in small groups on the modes of thinking and methodologies of each discipline represented.
- Asking each student to identify the strengths and limits of their discipline when first forming teams.

The suggestions heavily suggest the students identify with a single discipline, which is not the target of the course in design. Nevertheless, these are amongst the few concrete suggestions in the literature targeting *students*. The discussion ideas can also be used as indicators of students pondering disciplinary orientations and as such, an indicator for students noticing the presence of multiple disciplines or disciplinary actors in the setting.

The ability to discuss a problem without belittling or judging contributions through the lens of one's own discipline is difficult; this has been highlighted as a key interdisciplinary interpersonal skill by many (e.g. Stokols 2014, Heikkilä 2014, p. 52, Chari 2014, pp. 148-151). Chari's examples of nanoscience students' difficulties were often related to one of their thesis advisors exhibiting "disciplinary egocentrism", but may transfer into student-student discussions. Already first-year students from different fields may speak notably different languages (Bialek & Botstein 2004).

Reich and Reich (2006) compare interdisciplinary collaborations and encounters to multiculturalism. They evoke intercultural competence as a skillset that people working in interdisciplinary settings hone and learn (but never master). It is the opposite of disciplinary egocentrism; a sensitivity to the other cultures (disciplines) present, and the actions that do not place one's own discipline's traditions or contributions above another's. They also discuss the presence of power in interdisciplinary collaborations; both in terms of the people and their careers involved, but also on the level of the disciplines (Reich & Reich 2006). An example of this power imbalance in disciplines could be toxicology; the toxicologists' experience in the article by Kurath and Maasen (2006) is that toxicology is always in a supporting role, rather than a main actor, in collaborations with another discipline.

Interdisciplinary conversations have been studied amongst faculty (Strober 2011, pp. 129-130) but the discussions between students from different disciplines or students associated with an interdiscipline such as nanoscience have not, to my knowledge, yet been published on. Strober describes faculty seminars with participants from various disciplines and approachable, multidisciplinary topics (such as Ethics, or Representations). Her analysis reveals the deep-rootedness of disciplinary habits and thought, down to the inherently different ways of working with reading material or contributing at a seminar, and she describes the conflict arising from the different habits clashing. These habits of mind are discussed by many authors interested in disciplinary researchers put in interdisciplinary situations (e.g. Becher & Trowler 2001, Becher 1994, Lattuca 2001, Margolis 1993). Becher and Trowler (2001) write of the disciplines initiating their young members into these customs and habits. A study of graduate students and new faculty taking on an interdisciplinary context showed that the students and new faculty initially had a more open stance and spoke readily e.g. about learning the languages of other disciplines (Gardner et al. 2014).

Would the habits and vocabularies already sit deep in first or second year students in sciences? If so, those could be spotted in a discussion in the laboratory setting, where students refer to their disciplines or disagree about the actions they should take.

3.1.2 Recommendation: Interdisciplinarity alongside disciplinarity

The majority of papers, position papers and summaries arrive in the same conclusion: to do study in an interdisciplinary area, some foundations and a working knowledge of all relevant disciplines are needed. To have something to offer to the interdisciplinary discussion, one needs some disciplinary specialization and expertise to draw from (MacKinnon, Hine & Barnard 2013, Derrick, Falk-Krzesinski & Roberts 2011). Some recommendations go further, such as

> The aim should be thorough mastery of one discipline, perhaps two disciplines" (Eisenberg & Pellmar 2000)

even though they, too, debate on whether this thorough mastery is attainable in more than one field, if one is still talking about students.

Understanding the language and thought (epistemology) of a discipline is valuable (Spelt et al. 2009). These cannot be attained without an immersion in studying a single discipline and its disciplinary culture.

Balance between interdisciplinary and disciplinary studies are called out by several authors (Stokols 2014, Spelt et al. 2009, Augsburg 2006). The unit size in question is not a single course but a wider programme or minor studies; the authors have a favorable look on programmes that include both disciplinary studies and interdisciplinary parts alongside those. The way studies are organized in Jyväskylä seems to match this criterion very neatly, even if it stems at least equally much from organizational and financial reasons as from pedagogical consideration.

3.1.3 Recommendation: Team work skills and community-building

Building communication and interpersonal skills is a big part of working efficiently as a part of group. Student projects and student research are a natural platform for this (Caudill et al. 2010), but they appear only much later during the studies. Having students in research groups is also seen asto facilitate students' becoming part of the research culture and community, and it also helps students see cross-disciplinary connections (MacKinnon, Hine & Barnard 2013, Caudill et al. 2010).

In general, problem-based and active learning are good methods for team skills as well as interdisciplinary content education; an interdisciplinary problem makes it natural to include several disciplinary points of view and students to offer their expert knowledge. Communication skills and discerning vocabularies happens naturally with interdisciplinary group work and preparing presentations (Eisenberg & Pellmar 2000).

Certain personal qualities can be assets: respect and curiosity towards other disciplines and opinions, perseverance, patience (Spelt et al. 2009, Stokols 2014). It also means that not everyone will be equally interested in (interdisciplinary) collaborations.

Evaluating students on skills may need different methods than how content learning has usually been assessed in a course. Some scholars recommend that for group work, the whole group should share the evaluation, and if skills are the learning goal, then indeed skills (not only content) should be evaluated (Nagle 2013, Spelt et al. 2009).

On the topic of community-building, it has been noted that the interdisciplinarians struggle with fitting under one easily-defined label. For students, it brings safety and peer support to belong to an interdisciplinary peer group and bonding within this group should be helped via department-sponsored activities, student conferences or similar (Eisenberg & Pellmar 2000, Chari et al. 2012). Appointment to a home department provides safety - a place to fall back on if interdisciplinary studies or career do not take off – and thus support interdisciplinary ventures (Derrick, Falk-Krzesinski & Roberts 2011). It should be noted here that this is precisely how the studies are organized in Jyväskylä.

Perhaps a little outside the problem of course design, but the possibilities of encountering others from across the discipline are seen as fundamental for interdisciplinary collaboration. Regular contact could be ensured by seminars – they also allow faculty and students both to attend (Mobley et al. 2014, Eisenberg &

Pellmar 2000, Clark et al. 2013). Random encounters are made possible by cohabiting the same spaces; having common areas like cafeterias, coffee rooms, student areas, and sharing workspaces means more meeting people and more possibilities for starting collaboration (Science & Justice Research Center (Collaborations Group) 2013, Eisenberg & Pellmar 2000).

3.1.4 Recommendation: Cognitive and epistemic skills for interdisciplinarians

In the first chapter, the dilemma of an appropriate starting age / educational level on interdisciplinarity was introduced. McMurtry (2011) points out another dichotomy in writing about interdisciplinarity: seeing interdisciplinarity as arising from complexity of problems (highlighting robust disciplinary backgrounds), or as activity and dynamics amongst practitioners. He dubs these the “phenomena” and “knowers” perspectives and calls for study and education in interdisciplinary areas that would transcend these narrow perspectives.

What transcends is the meta-understanding of epistemologies and perspectives; being able to appreciate the more complete, if more complex understanding of a phenomenon by working to build bridges across previously incompatible (disciplinary) perspectives.

Some parts of this recommendation are related to the openness and readiness to accept use of other methodologies, epistemologies, and validity protocols. For example, Spelt et al (2009) write that for interdisciplinary work, it is necessary to abandon idea of absolute knowledge. In the same vein, others describe building tolerance for uncertainty and not having all required expertise oneself; building considerable trust in collaborators (Derrick, Falk-Krzesinski & Roberts 2011).

Doing this cognitive work requires practice in swapping between disciplinary perspectives, and generating integrated theory (e.g. Spelt et al. 2009, Larson, Landers & Begg 2011, Boix-Mansilla 2010). It is particularly challenging where epistemologies conflict (Stokols 2014); an example could be from computational study of large molecules – what is the feasible level of detail, “biology”, “chemistry” or “physics”? The kind of critical thinking required in fitting together theories is seen as rather experienced than taught - in venues such as journal clubs or seminars, where discussion of articles/research naturally takes place (Mobley et al. 2014, Eisenberg & Pellmar 2000). It’s a good question of how much of this could (or should) take place at the undergraduate level.

Complexity of subject matter and the fast developments of the field ensure that whatever the topic or methodology, it is unlikely that student will be expected to apply the exact same skills in the future. But the student will absolutely be expected to be able to integrate previous knowledge (Chari et al. 2012).

From the area of experimental interdisciplinary research within the sciences, some very general skills in demand might be understanding of the equipment and how it measures/generates results (Tala 2009); the design of an experiment to ensure data that befits the research orientation in a given discipline (Chari, Howard & Bowe 2012, Karsai et al. 2011); and the patience and pressure handling skills for working under pressure knowing the equipment or materials are expensive and results are needed fast (Chari et al. 2012).

3.2 Experiences of teachers/researchers and students in the field

To pinpoint relevant goals from the point of view of students and researchers already working in the nano-field, a small pre-study was done before and during the course design. A panel of students and researchers were interviewed, and their ideas were compared with the details of the study programme for nanostudents in 2011. The author reflected upon the collected information and used the ideas to shape the methods and goals of the course. The direction was from reuse of pre-existing material towards what the nano students were not getting elsewhere and what their predecessors considered meaningful for them.

The interview study was designed to get an insider view of the settings, both from the staff and the student point of view. The course design would be improved by understanding what nano staff and nano students perceive as routes into becoming nano researchers, and what kinds of skills they recognize that working and studying nanoscience requires. A reverse goal was also to understand what was perceived as less important, to help narrow down what the course should not focus on. Taking into account that we were designing a course of 2 ECTS credits, the content and amount of contact hours would allow for only so much.

3.2.1 Participants, methods, and data collection

Two expert panels were composed in early spring of 2012 to discuss these questions. The preparation and design phase for this course was short, and to be able to use expert ideas for the design, the panel was put together in a rush. That means the panelists were not a random sample. I invited people whom I was familiar with through Nanokoulu settings or based on recommendations by professor Ihalainen.

Three researchers with PhD degrees, working in departments of Physics and Chemistry, were the "Researchers" panel. The second, "Students" panel, was made up with four students, enrolled either in Master's Programme in Nanoscience or the National Doctoral Programme in Nanoscience (NGS-Nano).

TABLE 5 Participants in the expert panels ”Researchers” and ”Students” to discuss working and studying in nanoscience settings

	Pseudonym	Work / Study	Department of work or study
Researchers	Diana	lecturer	Chemistry
	Susanne	post-doc	Chemistry
	Joel	academy scien-tist	Physics
Students	Leyla	doctoral student	Cell & Molecular Biology
	Tom	doctoral student	Physics
	Mia	doctoral student	Chemistry
	Bo	master student	Nanoscience (Physics)

A one-hour discussion with a semi-structured set of questions was recorded with both panels, with the author as the interviewer. The group interview was a preferred method, as an insight from one group member could be expanded by different points of view of the other panelists. The problem addressed in the interview was defining the standards of action: what should be done in certain situations – choosing studies when striving to be a nano researcher, choosing students into a research group, collaborating with someone from a different discipline. The group members were asked for their own experiences as well as what they would recommend for others. As the invited group members had faced these situations pertaining to studying or working in an interdisciplinary nanoscience context, their responses are expected to be more reliable (Silverman 2001, p. 88). Still, taking into account that the group members were not chosen on basis of getting a representative sample of “typical” nanoscience researchers or students – if such would even exist – I do not expect to gain direct answers on how to put together a course. The information from the interviews will be subjective and aid in interpreting the local settings.

The interview findings will influence the course design. The participants can directly tell what they have struggled with in their education or their initiation into interdisciplinary research, and such concerns can be addressed in the course design. The interviews can also reveal habits that contrast with the literature on interdisciplinary work. Such instances need to be considered carefully in the course design; when the local researchers view this as beneficial it may be worth including or looking into in more depth.

The interviewees were mostly people with whom I was familiar with, and this posed some possible difficulties; as a partial insider having worked alongside some of the participants and working in their field, the responses might be inferring to a shared knowledge, making it difficult to make this visible in data. As I no longer was directly studying the same topics as they, but education, it however did not pose difficulties to ask “stupid” questions, which was noted as a possible insider interviewer problem (Adriansen & Madsen 2009), as my status as fellow researcher was not similarly at stake.

The group discussions were mostly transcribed by the author and partly by a research assistant. A basic transcription system was chosen as the focus was communicated ideas rather than the interactions during the panel. The chosen quotations in the following sections were translated to English by the author. The communicated ideas and thoughts of the researchers and experienced students are below arranged around themes of identity, disciplines, acquiring relevant expertise/skills, and community building.

3.2.2 Talking about nanoscience, identity and disciplines

The "Researchers" panel first discussed their identifications with nanoscience. They each mentioned hesitating using the word "nano" when describing themselves.

Diana: I never actually felt like I was a nanoscientist. […]
Susanne: No, well, I wouldn't introduce myself as a nanoscientist either. […]
Joel: […] My number one identity is physicist, and the nano, well, it comes on a need basis.

They provided similar reasoning for these statements, such as that nano was only relevant to them as the scale of the items they were studying, or that they had not intended to study the nanoscale as much as they had drifted towards it in the PhD phase or after it. Joel mentioned that he recognized "nano" as a buzzword or a trend, but already a falling trend. Susanne seconded this notion. They felt it was a useful word to use when describing work to laymen, that it carried better connotations than other choices.

Joel: It's easier to explain to grandma and grandpa, that you're, like, since nano is a little all over the place, like --
Diana: Mmm.
Joel: If you say physics, they go ahhh, nuclear physics, nuclear bomb, or something, but nano is like, there's the mental picture of something futuristic, something that's going on, in the now, so it's maybe a kind of better word for it.

The "Students" panel started off in a slightly different tone; the participants had had the intention to study nanoscience, even though often with an emphasis on one of the disciplines. Only one offered the metaphor of drifting into a nano topic. They had a hunch that the people having studied in the Nanoscience Bachelor program would have a wider field of expertise:

Leyla: The way I see it is that nanoscientists too have a strong one-discipline specification. That if you're working with a nanochemist she clearly thinks about things from a chemistry point of view, physicist from physics, biologist from biology. Maybe those who've been in the programme since Bachelor's level, they might think a little wider, but many have still, well, I'm doing my thesis and so forth, and in practice you sure can tell which area people have their main expertise in.

And while they were positive towards the idea of collaborating across disciplines, they remarked how they haven't done it themselves:

Tom: Well I haven't really been in contact during my studies or research with much anyone but the physicists. – I haven't really had the need to know any bio stuff or chemistry stuff.
Bo: Yeah, me neither, I haven't been in contact with others, either. But if I come back a little then it depends what kind of job you end up with and I might've been a little interested in this biology and physics connection, but it's still quite, there aren't many people doing it, and now I'm working for [a senior researcher] with pure material physics, so I don't think it [--]. There's not much interdisciplinarity, yeah, it depends.

The students did provide examples of people whom they felt were acceptably interdisciplinary – so they did see this in others and they felt it was a realistic goal. They could also pinpoint some issues in working across disciplines:

Mia: it's.. it's quite fruitful. Sometimes, of course, you hit terminology, terminology it's something that comes up a lot, when you talk about the same things but with different names.

and also

Leyla: Maybe it's the shared terminology. Since I don't know the spectroscopy methods, so I need to understand a little of what they're used for altogether, and they might not know so much about the materials, in general. It's the difference in theory backgrounds maybe. That so far it's been combining methods from different areas.

The researchers had some personal experience of these struggles, sharing examples of attempts that didn't work out as they expected:

Joel: A few years back we were supposed to have this collaboration, with [professor from another university], we were modeling [large organic] particles which had like ten to the power of x atoms, and we had to, like, do electron structure calculations --
(everyone laughs)
Joel: -- and we did something rather in the ballpark. It didn't work out since the shared ground was so far out. But it was the first tiny attempt to collaborate.

and

Diana: I was considering a project that was related to cell membranes, and other similar biostructures, and, like, their measurements with femtosecond methods. So I was doing some groundwork about what they'd done and what it's like but I didn't end up there… biology, to me, is a little scary --
(everyone laughs)
Diana: or if to you [points at Joel] it's like the chemists are simplifying things, the gap, gap between chemists and biologists --
Joel: yeah it's, like, even --
Diana: they have like, huge, the molecules and everything. And you make

membranes from the molecules and stuff and when you start to think about it as a chemist, well, the whole thing just blows up!

Susanne: Yeah there's quite a gap when you go for such complex systems that they self-organize.

The researchers noted the vocabulary or terminology issues same as the students, but they had experience of going beyond vocabularies. They could point at the discipline-driven expectations and limitations of methodologies that were difficult to understand by their collaborators.

3.2.3 Tools and skills: The Information Technology (IT) versus math debate

When the panels were asked to share ideas about studying to become a nanoscientist, they talked about their own study paths and the role of Information Technology (IT) in their research. The researchers also reflected on their experiences in selecting students and tasks for summer projects and research internships. In general they expressed that having taken a particular course or having a specific set of knowledge was not as much of importance being excited and able to learn.

Diana: Not anything whatsoever [can be overlooked], like if you come in like, I haven't studied any physics –

Susanne: I'm from psychology and really interested in this nano—

Diana: that might not fly. But not a particular course, not in the beginning. You could take the course during the project if it's really important for the project, but there's always time later to learn things.

[…]

Susanne: I'm really grateful to [my thesis supervisor] who took me in even though I couldn't use the operating system when I started. She had to walk me trough and I'm sure she was so frustrated [laughter], but on the other hand it didn't take that long, I made lists of the commands and I taught myself to do it. So I don't think a thing like that should limit the student, if in one area she is lacking, because, well, if you're an experienced student, you can catch up fairly quickly.

They did bring up examples of courses that give students understanding of new methodologies for experiments or computations, and that they're interested in whether a student has this experience mainly to decide on appropriate tasks for the student, rather than to rank out students. The student panel echoed the same sentiment.

Bo: […] I was working on computational material physics and I hadn't even taken the course, so, It didn't really seem to matter, since the grounds on which I made it to the research group was that I'd studied a little bit of everything and especially programming. […]

Tom: In our group it's the same thing, programming skills, they're a huge plus. And then I don't think there are really, not a lot of physics courses where they deal with our topics, so the courses are more for learning methods and the right sort of thinking. So if you've got that, that's great, and if you're interested in what the group is doing, that's a big plus too.

and

Mia: But what skills afterwards, if you're joining the research group, you need something more certainly than that you can work in the lab. You have to have the social skills like for functioning in the group. […] You need some amount of communication skills, and and… well I'd say they're surprisingly important when, even though you're good at doing things, it isn't necessarily enough.

Bo: Yes and of course, well, when some groups take second year students as interns, well they have not really been up to much anything. And especially like last year we applied so that there wasn't any written component or CV but the only thing you show is your grades and [ECTS] credit points so that – or, I suppose, it does show you're maybe interested if you've studied a lot and got the credit points.

The researchers also mentioned communication skills and presentation skills as a big part of their job - one they had not had chances to apply in their Bachelor or Master studies.

They were asked to think about the problem from the point of view of starting nano-students. The researchers reflected on the increasing importance of computational skills and the importance of solid mathematical thinking, which they thought often wasn't the students' priority:

Diana: […] when you think about how much maybe mathematical topics they'll have to-- in the nano programme, because of the scale, the models that they use, that they'll have to use. So that many might, you know, those rascal chemists, skip the math since so few are that interested in it in itself, so…

The student panel members spoke of the importance of mathematics for theoretical work becoming clear through studying more mathematics.

Bo: For me it was like, I don't now where it got started, but then I kind of happened to go to the maths and IT departments. So now I'm working on my specialization studies in maths. I don't know how it happened really, but I got more and more interested in it. And then of course I started getting it that if I'm going to do something theoretical, then that's like, it's a substantial part of that.

On suggestion that maths and computer science courses are competing for student attendance, they debated the functions of each:

Joel: I would absolutely choose computer science, since it is still, whether you do— if you do experimental, but the computer is such a big tool. Especially of course if you're doing numerical or computational. Or even if you're, not purely computational, but still you need numerical skills.

Susanne: I find it hard to – I don't actually agree. I've seen on [a physical chemistry course] how students are just lost with basic maths, so. You get the feeling that, well… somewhere you've taken the wrong path.

Diana: I don't know if the physicists, the nano physicists, if they have the

[mathematics courses for physicists] or what do you call it. They've put it into those courses, but that's, don't the physicists get those skills there anyway, since… for chemists we try to say that "now you go take this course" because it's most useful for the maths perspective, like a tool for maths, so you try to recommend those courses that they'd rather take those. It's not mathematics as a science but as a tool. As for computer science, I've never taken a course, I've learned the programs, I've done experimental work, well, I get it that in modeling or such it's different, but I've learnt everything by just clicking, seeing how it works, asking someone if I didn't get it.
[…]

Joel: I meant more like this theory side of computer science, numerics and the sort… like using software, they change all the time, there's tons of it. But for maths, now that I've taught on the first course, I've noticed that the biggest thing for not getting maths is not understanding what they're calculating. That when they get the physics concept it makes it so much easier.

Diana: I feel that for chemists it's the other way around, they get stuck in the "OMG it's math's I give up", and they cannot get over it to get the phenomenon, that they just throw their arms up in the air.

They expressed two ways to think about mathematics and computer science in use of scientists; to use them as power tools to use in prescribed situations (Diana's advice for students), or to study them as a specialist, to have an intuition in knowing what kind of approach would work in which situation, and to develop new approaches. The latter sentiment Joel expressed above on computer science, and together with Susanne later on in a discussion on math. This intuition was probably what Bo was hinting at in saying he realized how relevant mathematics was for his studies. This connection and relevance was seen as all discussants to take place at the end of master's degree phase.

3.2.4 Tools and Skills: Becoming an experimentalist

Experimentation was approached in a different manner; the experience of working in the lab was seen as a requirement for entry into some research areas. It was treated as an acquired quality of the person, one that the student could prove he or she had:

Leyla: Well, for us it's like important for molecular biologists to have a lab background. With us the students are typically interns and master students or at least they are master students before they're taken in for doing a thesis. So that you see they can do the thing and can function more or less independent. And like, good English skills and if you've got the IT skills, that's a plus. And like, interdisciplinary or that sort of ability, it's certainly not a bad thing, but the effort needs to be in laboratory molecular biology, so that's a big thing for us.

Mia: Yes, I think it's for us too, in experimental research it's – of course I don't know how people are originally chosen for these projects, but often from some internship. We chemists have the [advanced practical laboratory work course] which is a good, a good way to show your experiment skills, or a passion for wanting to do the job. [--]

The students had a view of the internship as an unofficial entrance into further studies or thesis opportunities with a group. The researcher panel, too, noted that for some areas, previous lab experiences are used as indicators for if a student has the qualities for doing research in the lab.

Diana: Tell me about it. Like if you were looking for a student for the laser lab, she would still need to have some clue about spectroscopy. Of course you'd find out once she was there, there's quite a lot of this tangible - you need to have a grasp of this, this very particular way of working. You would test the person, with, like, a bachelor thesis project or something else, to see if they were up to it anyhow.

The lab skills were spoken of similarly to craftsmanship, a feel for the profession you either have or you don't. No panel member mentioned a specific course but the through work in the lab, under an experienced scientist's supervision - an apprentice model.

The researcher panel ended on the note that the amount of science knowledge one needs to stand on to contribute their own, original piece of work has grown substantially – they spoke of the basic studies as a grounding for this work, and the importance of offering something for "everyone" (experimental, theoretical, computational). Those studies should be starting point and then incrementally working towards making their own discoveries:

Susanne: This has shown, to me, that these students have very different backgrounds when it comes to having methodological understanding, just like... you start thinking that the studies should guarantee some kind of basic control of these, computational, mathematical [methods], all this fun stuff. It's probably quite challenging --

Diana: -- since there's so many things you should, like, and now that we've put a cap on study years and credit points too so to speak.

3.2.5 Networking and community building

The Students panel discussed the importance of being remembered by the teaching staff and that being the main venue into a research group. When asked for particular actions a student should take, they mentioned taking varied courses and working with many people, and asking around for thesis topics already in the Bachelor stage – this seems to translate to building an initial network.

The researchers spoke for a while on whether they thought a nanoscience community exists. This was directly after the author asking if they felt it's just people from different disciplines, working in the same building:

Joel: well, not entirely different. Of course you want to have… that they belong into an "us". But it's smaller, at least for me it's that.

AL: Is there such a thing as a team spirit?

Susanne: I don't quite think so. It's like these happenings, like the Nanoscience Center Christmas Party, I felt that there weren't so many biologists.

Diana: You get the feeling in the Nano building community that they're like, most of them are in the adjacent building, so they are not visible there as persons in the same way.
[…]

Susanne: Yes! Like, I don't think – I'm sure everyone gets along and there's a good atmosphere so you can ask one another if you're not sure about something, but there's not like spending your free time together which might be really fruitful in the sense of getting new ideas.

Joel: And also, it's such a big building that it'd be really incredible if the whole house had a team spirit, just like the department of physics, there's not like, there's a good spirit but you also get the cliques.

The student panelists reflected on their first experiences of attending nanoscience conferences:

Leyla: […] if you go to a nano-themed convention – I went to this student conference in Switzerland in 2009 – so it helps you tons to understand it if you have any knowledge of the other disciplines. Like otherwise when they speak about quantum computing and you're like oooh, what's that, and someone speaks about cellular stuff and the physicists are just out there. You should know some things from the other disciplines.

All interviewees expressed there was a good atmosphere in nanoscience in Jyväskylä, that people working in the field were open to trying to understand or helping out others. It was not perceived as a close-knit community in the sense that people would often have friends in the other disciplines. The traditions or actions their close colleagues were sometimes holding the students back from seeking these relations. The Christmas party, which the staff mentioned not having many biologists, was brought up by students:

Leyla: Yeah... I haven't been to it [the Nanoscience Center Christmas Party]. Maybe it's 'cause I'd be the only one from our research group there, so, it's not so easy to start going.

The few people who had membership in more than one discipline noticed they could act as bridge builders, but it also resulted in some difficulties on identifying themselves. Susanne reflected on her experience as having shifted her major:

Susanne: well it's a little bit like... the chemists keep to their own... or I mean, with the chemistry coffee breaks and everything, and then me, I'm some kind of, I don't know what I am. I have a physics background, so I'm somehow spending quite a lot of time with physicists outside of work.

The coffee hours that were probably meaningful meeting spaces for the nanochemists were setting a bar that Susanne was uncertain about crossing: was the titling of the coffee hour as "chemistry coffee break" done to keep others out or to inform others about whom they might find there?

The students had very down-to-earth ideas of how more nanoscience students or staff could get to know each other:

Mia: I see it so that the easiest way to get aquainted is just being, going to the events, sitting in the same coffee table, going to seminars, just talking. I don't think there's a shortcut.
Bo: Yeah well usually, if you're working in a team, that's how it builds up.
Tom: Students in particular, or like, during my study years I saw that when you're taking the courses and you've got these groups of people doing homework together, that's how you've gotten to know others best.

The students and the staff all brought up the Nanoscience Center wide seminars and an annual research seminar at the Konnevesi Research Station. These were described as fun and useful by attendants. There were still personal beliefs about the annual seminar being intended for a specific group, and the interviewed researcher had never before talked with a colleague about it:

Diana: -- but [the annual seminar] is just for the select few, really, so not everyone's been to that. I'm a little jealous that I've never got in.
Susanne: You never got in? Why is that?
Diana: Oh I don't know, maybe if I'd gone around telling people I want to be there then maybe they would've had me, but nobody's like asked me or said that you should go.
Susanne: I just signed up, like, is there still room on the bus?

It was not clear to all possible attendants whether the seminar attendance was based on application, invitation, or "just signing up". Thinking they were not viewed by a selection committee as suitable made them reluctant to bring the issue up before this interview.

This annual research seminar has, since this initial interview, been organized twice: The day seminar in 2013 at Hotel Laajavuori had a focus on post-doctoral researchers' work. The overnight seminar in 2016, back at Konnevesi Research Station, included specific sessions for PhD students and post-doctoral researchers to get to know each other's research better and on an informal level. They were included and designed based on senior staff recommendations (personal communications, S. Rauhamäki, June 20, 2016 and H. Lehtivuori, December 19, 2018).

3.3 Focusing the aims of the nanoscience course

The interview study was meaningful both in gaining suggestions and ideas from people experienced in working or studying in nanoscience, as well as insight into difficulties these experts had experienced in the interdisciplinary context. Against the background of the review of recommendations for interdisciplinary work or study, this chapter helps focus on the most pertinent learning goals for this course.

It was clear that the experience of belonging in a certain group was meaningful among both the students and the staff members interviewed, and some had experienced conflicts in crossing the disciplinary borders, or had found it impossible to cross some borders, especially when concerning informal situations such as coffee hours or parties. The conflicts and difficulties were so evident that the interviewees did bring them up – against the initial worry that I had that they might come to the interview channelling some kind of an ideal nanoscientist. Perhaps the only trace of this was how both groups said the Jyväskylä Nanoscience Center has a "good atmosphere BUT".

The concrete suggestions the interviews gave in terms of enhancing collaboration was to encourage students making homework together and participating in joint events or seminars. The researchers' discussions about who belongs to which coffee group or is invited to a seminar made it clear that the possibility of not being an *intended* part of a group or even being *not wanted* in the group is lurking where people are not directly assigned or invited. This made it clear that in the course, student groups should be assigned by the teacher and teaching assistant (TA) so that the students would not experience this.

The students and researchers brought up having different vocabularies in the different disciplines and the need to learn some of the vocabulary. The student panel pointed out that some factual knowledge of important topics in the other disciplines should be expected of the students. These help formulating a learning goal on recognizing and using terminology from other disciplines, and making connections between concepts from different disciplines that share a meaning (or homonyms that mean different things for different disciplines).

The researchers explained about some difficulties in collaborating – related to the different sizes of objects, or levels of detail attended to, in the disciplines involved.

It was interesting that both students and researchers brought up the idea of using knowledge of another discipline as a "power tool" in another – mathematics and computer science, in particular. In design of the laboratory sequences, is there something that could be done earlier to aid the students in seeing the need for certain "power tools" or the combination of subjects? One criterion in choosing or designing laboratory works should be the explanatory power of mathematical or chemical modelling in solving otherwise very qualitative problems.

The suggestions and experiences explored in the researcher and student interviews, in a more condensed form, are listed in TABLE 6 alongside the points offered in research literature as recommendations.

TABLE 6 Sum-up of recommendations from literature, local researcher/teacher interview, and local students interview

Thematic area	Literature recommendation	Comes up in researcher / teacher interview as	Comes up in student interview as
Power of encultura-tion in a discipline	Explicit discussion about forming habits related to culture of a discipline	Different vocabularies with roommate Comparisons of level of detail (gaps between physics and chemistry, chemistry and biology)	You can tell which speciality a person has "physicist thinks from a physics point of view"
	Reflection on what it means to be a practi-tioner of one's own dis-cipline	What my relatives think I do if I say "physics" Rascal chemists who do not enjoy math	Nanoscientists as hav-ing a strong discipli-nary orientation
Interdisci-plinarity alongside discipli-narity	Studies should be orga-nized to include both	-	One needs some back-ground from each dis-cipline to understand conference presenta-tions etc.
Team work skills and com-munity building	Dept / Faculty sup-ports belonging to in-terdisciplinary peer group	Chemistry coffee hour, changing disciplinary orientation Not being invited to Nano research seminar	Being the only one to attend the Nano Christmas party Building relations in homework group
	Appointments to home departments for stabil-ity and security	-	-
	Problem-based learn-ing, group work to practise team work & intergrate viewpoints	Nano research seminar Student summer intern-ships	Student summer in-ternships
	Culturing openness and trust in collabora-tors	Openness to mathemat-ics and/or IT	Openness to mathe-matics resulted in good things Not having had the need for collaboration thus far

Table continues on next page

TABLE 6 (continued)

Thematic area	Literature recommendation	Comes up in researcher / teacher interview as	Comes up in student interview as
Cognitive and epistemic skills	Practise swapping between epistemologies	Discussions with roommate from different discipline	Learning spectroscopy and combining methods
	Managing conflicting theories, finding/building shared ground	Modeling molecules was difficult without shared ground	Contents of courses taken not as important as having learned the “right sort of thinking” that can be applied elsewhere
	Learning critical thinking through discussion of research / articles	-	-
	Learning equipment and its measurement/generation of result	The need to “test” prospective group member’s lab skills, Learning computational theory	Importance of having a “lab background”
	Designing experiments with validity protocols of discipline in mind	Would “test” prospective group member’s lab skills “A very particular way of working” in the laser lab	Importance of having a “lab background”

These findings are next applied in the design of learning objectives in section 5.1, where also the relevant ways of attaining these goals or practising these skills as outlined in chapter 4 are included in the design.

4 WHAT DOES LEARNING LOOK LIKE?

Approaching the course development from a design point of view, a locally appropriate theory of learning is in order to design relevant learning activities or constructs to jump-start such activities.

Cobb et al. (2003) calls on the situatedness of findings of design-based research. Sandoval (2004) narrows the theoretical, initial understanding of learning down to what is appropriate in the application of designed learning sequence. The theory of learning need not encompass everything but to speak about learning within the constraints of the local environment and the design. Here we explore learning as it might inform design of a learning-sequence in an interdisciplinary, higher education setting, involving group work and collaboration.

4.1 A local theory of learning

Sfard (1998) sparked something by pinpointing two metaphors for learning – "acquisition" and "participation". Her article considers the effect of the metaphor we consider, when thinking of learning, on our actions in teaching or research. While she describes the meanings and actions involved with each, she points out that her intent is not to say the two are incompatible. She relates the differences of these viewpoints to differences of some two sciences explaining a phenomenon; on the surface level, incommensurable - yet when put together, giving a richer picture. She shoots down the idea of one metaphor to cover the entire theory in the field of learning and writes, "we must learn to satisfy ourselves with only local sense-making" (Sfard 1998, p. 12).

What is local when it comes to a theory of learning? Interpret from the point of view of the (design) problem at hand, it is the relevant learning theories that help construe useful tasks and materials for learning around this particular issue, such that lead to the wanted results. It may not be local in terms of fitting neatly inside one disciplinary or philosophical orientation.

The metaphors bear some resemblance to the division of talk or research on learning as cognitive constructivist (or cognitivism) as opposed to socio-constructive (or socio-cultural). They, or the underlying individual–social dichotomy, are concerned with the very mechanisms of learning. Characteristics of these theoretical orientations are outlined in TABLE 7. The listing is adapted from a review of research on group cognition and its perspectives (Akkerman et al. 2007).

TABLE 7 The cognitivist and socio-cultural stances on research on learning, adapted from Akkerman et al. (2007)

	Cognitivist perspective	Socio-cultural perspective
Views knowledge as	A state (having in common)	A process (continuously negotiated)
Focus of study	Individual subjectivities	Joint activity
Views process of learning as	Unification of participants' subjectivities	Coordination of contributions
Preferred result	Consensus	Diversity and dynamic unity

Within this thesis, learning of the set goals is considered from the socio-cultural perspective (e.g. Akkerman et al. 2007, Lemke 2001). This is since the design task is mainly concerned with collective, social learning goals. While some learning objectives related to interdisciplinary competences are more individual cognition oriented (such as learning to recognize conflicts between theories or concepts from different disciplines), they are not strictly among the learning goals of this first-year course.

4.2 Science education research informing nanoscience education

In spirit of the Interdisciplinary Research Process model, the disciplines relevant to the design of the course must include the Sciences in overlap with education. The Science education research has informed choices in this course through the pre-existing learning materials (their initial design) as well as the design of new tasks for the course. Some choices made without much thought given are, in retrospect, the result of all those involved in the course design having studied in the Sciences.

The structures of the three disciplines – physics, chemistry and biology – involved is relevant to being able to teach them. They all have their own core ideas and a particular structure in which the knowledge is organized. The ways of gaining knowledge, i.e. the epistemology, in each subject is also different – although the Sciences share many of the same values and principles (e.g. Repko 2012, p.114). The aforementioned ideas, combined with the knowledge of how these ideas are best presented to learners, an understanding of common learning difficulties in the subject matter and what gives rise to them, constitute the subject-specific Pedagogical Content Knowledge (PCK) coined by Shulman (1986).

In designing or choosing learning materials for the it would be useful to not settle on delivering relevant content knowledge, but picking materials that support the teachers or TAs in teaching choices in subjects they are not experienced in teaching. To be attuned to students' possible difficulties in a concept would help the instructors set expectations - as well as expect to spend more time unravelling certain problems, or gliding through others; to have knowledge about what kind of teaching or student support material there is and how to choose among it (see e.g. Van Driel, Verloop & De Vos 1998, Hill, Ball & Schilling 2008, Shulman 1986). This poses a definite difficulty for this course design; the TA:s would change yearly and typically not be expected to have a teaching background, and the teacher initially was familiar with physics only.

Confining the science educational information into a smaller, nanoscience educational viewpoint, I will offer a short overview of what the current state of research in nanoscience learning and education looks like in topics relevant to this thesis.

A big advance in nanoscience education came through the development of a framework of ideas appropriate for high school students to learn about nanoscience. The effort of nanoscience educators, nanoscientists, and technology experts through multiple workshops and expert interviews resulted in the collection of 9 Big Ideas of Nanoscale Science and Engineering (Stevens, Sutherland & Krajcik 2009). The framework explains ideas that are basic for understanding the nanoscale, such as the surface-to-volume ratio and how it affects physical or chemical properties when scaling down to the nanoscale (the Big Ideas are listed with illustrative examples in section 5.3.1.) Continuing in this vein, the important concepts or topic areas for teaching nanoscience have been addressed by several nanoeducators through expert and teacher surveys. This work has given nanoscience education a basis for a curriculum designer to work on, even if the practical applications of this body of work take different approaches and emphases. The Big Ideas come as close to a canon as there is at the moment.

The research into nanoscience learning has provided information similar to the Science Education research tradition; we have understanding of common misconceptions or difficult areas to learn, and many examples of successful research-based learning progressions, as well as repositories for sharing singular pieces of learning materials. Some examples of each strand are in order:

Known difficulties in nanoscience learning e.g. the difficulty to operate at very small – compared to a human – scales. Tretter and colleagues found that science experts and gifted high school senior students were using unitizing (utilizing a new or a pre-conceptualized unit from objects relevant to this scale, such as a light-year at larger scales) as an aide to compare sizes of objects at specific scale, while younger students did not utilize this technique. Even with this, participants not familiar with nanoscience performed rather poorly at tasks requiring one to imagine objects of a certain size (Tretter, Jones & Minogue 2006, Tretter, Sweeney & Seal 2008). In his thesis, Delgado (2009) describes four areas of thinking about scale: through ordering, grouping, relative scale and absolute size. He expects students to have a grasp of the scale of objects on all four areas at the end of high school, which is the level of students in the course in development.

Another area that has attracted considerable interest has been the students' ability to interpret pictorial information and to recognize features of modelling in an image or simulation of a nanoscale object. Laherto (2008, 2018) reports of study where laymen visiting a science exhibit were asked to interpret typical electron microscope images shown to exhibit visitors, and it turned out that the interviewed visitors were treating them in photographic fashion. The confusion between what constitutes an image, a model, or the phenomenon perhaps began as the imaging possibilities have gotten more accessible and the microscopist as a profession become nearly obsolete. The understanding of image or simulation production is no longer as necessary to obtain images, and therefore images are produced by people that have difficulties interpreting their meaning (for historical perspective, see Mody 2004, Lenhard 2004, Pitt 2004, for a contemporary example of difficulties interpreting microscope imagery, see the "stripy nanoparticle" controversy in e.g. Stirling et al. 2014).

A few learning progressions in nanoscale science have utilized educational research in their development stage, or have otherwise received attention and research after the materials' formation. For example, Delgado's doctoral thesis involved development of instructional activities for learning about scale (2009), while Sederberg (2012) generated a detailed understanding of how students progressed in learning to model (also nanoscale) magnetism using a certain set of learning materials, his work furthered by Harmoinen on highlighting the teacher's actions in the process (2013). Mutambuki (2014) studied the attitude change in undergraduate chemists being exposed to a nanochemistry context on an experimental work course. She showed how exposure to self-designed improvements, and results that were not obviously pre-determined, helped students see chemists as flexible and chemistry as involving improvement and design of methodology, rather than a static field with standard procedures.

Several learning progressions and examples of laboratory work instructions are published as articles in the domain of nanoscience education. To ensure access for teachers, databases for compiling them for the interested teacher are hosted online, such as the NISE (National Informal Science Education) Network and the nanoHUB[4]. Universities with nanoscience education research may offer other material for educators, such as the video manual repository at University of Wisconsin-Madison[5] or the online course materials compiled by Nanokoulu [Nanoschool][6]. The dissemination of nanoscience educational material has also progressed through nanoscience education projects or programmes, such as the EU projects NanoYOU and IRRESISTIBLE[7] or the U.S. based educator training programme by NCLT (National Center for Learning and Teaching in Nanoscale Science and Engineering, sponsored through the NSF)[8]. There are materials from

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4 http://www.nisenet.org/ and https://nanohub.org/, respectively.
5 https://education.mrsec.wisc.edu/video-lab-manual/
6 http://www.nanokoulu.net
7 https://nanoyou.eu/ and http://www.irresistible-project.eu
8 http://www.nclt.us/

elementary to tertiary education available, and for most nanoscience topics that come to mind there are ideas or examples for education.

Many educational lab materials are directions for producing a certain nanomaterial or reaction, with perhaps safer or inexpensive materials better available at high school level. There is also a strand of nanoscience educational materials with the idea of making the invisible, submicro scale of the nanoworld visible through on some aspect analogous models. These include varied – sometimes tangible – models of a macroscopic system. These attempts to find analogies apply to many regions, such as illustrating the function of Atomic Force Microscopy (e.g. Lindell, Anssi & Kähkönen 2013, Lindell, A. & Viiri 2009, Planinsic, Lindell & Remskar 2009, Planinšič & Kovač 2008, Euler 2008); understanding resonant quantum mechanical wave models by analogy to coupled oscillators with external harmonic forces (Joe, Satanin & Kim 2006); or using a tuning-fork analogy to imagine resonance of surface plasmon vibrations in metal surfaces (Muniz & Oliver-Hoyo 2011).

4.3 Talk and interaction as the basis for learning

There's a good amount of studies on the kind of student talk that is productive for learning in classroom. Some salient features go across class levels; while the expression and enactment are different in kindergarten or university classes, the underlying purpose is still the same.

There are at least two large bodies of work on the kind of collaboration and talk that has an effect on learning. Here, they go under the names of "Accountable talk" and "Group thinking", and while sharing many ideas, there are some critical differences. Both have their origins in Vygotsky's founding idea of talk having two functions: talk as a communicative tool for sharing and developing knowledge - and as a psychological tool for organizing thought, reasoning and planning. They are evidence-based strategies, founded on sociocultural discourse analysis of talk situations – not only linguistic but also the non-verbal and social relations of the pupils or students (Mercer 2004, p. 141).

"Accountable talk" is a set of practises that foster participation and academically productive talk. The idea is for the class to internalize certain norms or supporting structures for discussion. The practices involve three accountabilities, which have a precedessor in discourse ethics and critical pedagogy (e.g. Habermas 1995, Leeper 1996, Huttunen 2003, pp. 72-81). The discussants are accountable to the learning community, to standards of reasoning, and to knowledge (Michaels, O'Connor & Resnick 2008). Accountability to the learning community means that the participants listen to others and use their contributions in building their own response. Accountability to standards of reasoning means the drawing out of explanations, showing premises and challenging such, as well as self-correction. Accountability to knowledge deals with the expectation to use facts as a basis of discussion. The students make the evidence for their claims explicit and learn to use sources of information that others can verify. These accountabilities are tied in with one another; they produce the atmosphere and the learning environment of the whole group.

The "Group thinking" methodology for creating talk that is more productive also consists of supporting structures for discussion. The creators of "Thinking Together" programme argue that giving learners a set of ground rules for conversation is constraining in one sense, but liberating in another, making it possible to overcome e.g. individual social status differences and alleviating the threateningness or challenging one another's ideas (Mercer et al. 2004). The programme aims at producing more genuine dialogue between the learners by providing the ground rules for discussion, so that the learners can focus on advancing their understanding of the scientific topics at hand rather than the social circumstances.

The focus on talk as central to learning science is founded in works of Lemke (1990) and Bakhtin (1986), who emphasize that different modes of discourse are used for different areas of society. Lemke views talking science is speaking in a specific mode, which is influential to our understanding science altogether (although he suggests that there is a great communicative benefit to be had from not adhering to the mode of science reporting) (Lemke 1990, p. 133). The epistemically oriented views for talk in science come from many different walks. Argumentation and rhetoric in science learning are modelled after sociological, linguistic, or anthropological studies of science and scientists. One resource are the epistemologically selective abstraction techniques in science, e.g. thought experiments, limiting case analyses, imagistic reasoning, and analogies (Nersessian 1992), or narrowing down factors to the few that have most influence (Rowbottom 2011). Such are perhaps more thinking than talking tools, but may present themselves in talk as support in problem-solving, particularly in a problem involving parts that cannot be simply looked at or tried out. Argumentation (see e.g. Erduran & Jiménez-Aleixandre 2008) is often highlighted for its usefulness to give structure to scientific discussion and clarify the roles of evidence and explanation (Duschl 2008). Duschl juxtaposes it with final-form science, where the goal is to memorize final-form statements ("facts"). Argumentation indeed helps to see the formation of established scientific knowledge as an activity involving negotiation and people, and to relate the classwork to what scientists do (Jiménez-Aleixandre & Erduran 2008, Sandoval & Millwood 2008). McDonald and Kelly (2012) argue that focusing on the argument structure gives a much too narrow view of scientific discussion; there are many other ways of participating in science, such as learning observation skills or distinguishing between acceptable and inacceptable evidence, often through other kinds of language use.

It should be noted that the three categorizations above are not exclusive. The proponents of viewing science learning as initiation to talking science see group discussions and dialogue as a major part of classroom work (Lemke 1990, pp. 168-169), and the researchers whose starting point is dialogue, are including the characteristics of logical argumentation in their descriptions (e.g. Michaels, O'Connor & Resnick 2008).

For the purposes of the task of designing a learning environment and a learning progression in nanosciences, the different characteristics of productive talk are thematically outlined in TABLE 8.

TABLE 8 Collected characteristics of talk that is productive for learning (Lemke 1990, Mercer et al. 2004, Michaels, O'Connor & Resnick 2008, Nersessian 1992, Wegerif et al. 2016)

Theme	Accountable talk	Group thinking /Thinking together	Science talk as genre	Speech descriptors
Peers	Accountability to the learning community: building on others' contributions.	Encouraging each other, actively seeking agreement. Respectful tones. Expressing intuitions.	Inviting knowledge from expert, negotiating expertise.	Asks peers for contribution. Mentions a peer contribution in one's own turn.
Argument and logic	Accountability to standards of reasoning: structuring contributions as arguments.	Elaborating explanation, making one's reasoning clear.	Using relevant abstraction techniques to solve problems. Constructing coherent arguments. Expressing logical connection, classification or taxonomy.	Elaborates on reasoning. Uses an abstraction technique. Forms an argument.
Knowledge	Accountability to knowledge: presenting only ideas with strong faith in.	All relevant information shared, alternatives negotiated. Open questions, expressions of humility.	Negotiating of what is acceptable as (valid) knowledge or evidence. Differentiating between theory and observation.	Offers a fact. Admits not knowing. Negotiates choice of point of view.
Affect	-	Warm positive affect with shared smiles and laughter.	-	Laughs (warm, not mocking). Shares a story.

4.3.1 Focus on student talk in this study

While the role of teacher in any classroom is different from that of the student, the main communicators of interest in this study are the students. The teacher(s) should certainly abide by the ideas of dialogic or communicative teaching outlined above. The teacher(s) in this study are perhaps unusually close to the students' levels of knowledge in the sense that the participants have very different disciplinary backgrounds and expertises. In some topics, the teacher and TA will have a deep knowledge resource, while in others it will be the *students* who have the knowledge resources to share. The teachers' communicative competence becomes more important than their knowledge resource. It is when the teacher(s) must refrain from an authority position and support the productive talk of the student groups themselves. It can become an instance of dialogue where participants – students and teacher(s) – are on an equal standing for decision-making, much as in the original, hardly attainable, ideal communicative situation (e.g. Leeper 1996, Huttunen 2003, p. 75). In line with the social learning goals of the course, I am particularly interested in how the students act when left amongst themselves. The decision to not analyse teacher(s)' actions further is to put weight on observations on students' interactions amongst themselves – while, in analysing them, remaining aware of an influence from the teachers' actions and presence.

5 PILOT COURSES AND PARTICIPANTS OF 2012 AND 2013

The big influences of the Context analysis, Need analysis and our higher level conjecture of learning are all ingrained in the design of the course.

To sum up, from exploring the context, I know this course is the precedent of nanoscience courses exploring imaging and molecular interactions. I also am made aware of how this course is the first and possibly only occasion where the students in the Nanoscience Bachelor's programme are introduced to one another as nanoscience students during their Bachelor degree. This strips away most of the focus on teaching and assessing nanoscience "content" and puts the skills linked with and awareness of interdisciplinarity into the center. The content is there insomuch as it is the context of student activities.

The initial course also was not a summatively assessed course – it was a pass-fail based on attendance and completion of course excercises. The summative assessments were dropped in agreement with the department: in their view the course was to provide a readiness for studying in the nanoscience programme, and in the viewpoint of this study, giving formative feedback to students and time for hearing their views on this course and interdisciplinary science was more important than devising a measure of learning gains for the course.

From conducting a need analysis, I was willing to look at ways to include all items in TABLE 6 into the course. I was informed of the importance of feeling welcome in the group. And I was given a topic to consider; based on the reserachers and students perceived benefits from both mathematical and IT skills, could I include instances of modelling and highlight the uses of mathematical and computational skills in nanoscience?

And through framing how students learn through learning as participation in the group's sense-making, context-dependent, and exploring the detailed understanding on learning nanoscience as well as learning in group settings, I can start drafting a design that shows how exactly we envision the students of the course to attain these learning goals.

5.1 Problematic initial design attempts: emphasis on modelling

During the initial course design of 2012, the development of modeling skills took a very strong role as a way of measuring students' learning of nanoscience content and ways of thinking. A draft of this design is shown in FIGURE 6, showing the whole learning sequence wrapping around understanding mental and external modelling, and practising modelling in groups. This picture is not entirely truthful; the design was more balanced in 2012 already, but the evaluation of goals was intended to happen through the evaluation of students' drawn and expressed models.

This heavy emphasis on modelling as informant was diminished in 2013 as it became clear that the balanced course materials did not offer enough grounds to evaluate the students' skills in modelling, despite attempts of including exercises with prompts to "draw" or "model". The variance of topics, as befits an introductory course, meant that there was no focus on building a single model, Consequently the construction of any one model was a once-off event, not lending to analysing its developments. And to consider development of modelling skills through modelling first images, then chemical structures, then mathematical formulae use, then a graph, and lastly using a computer simulation – needless to say the data acquired was much too varied for the intended purposes.

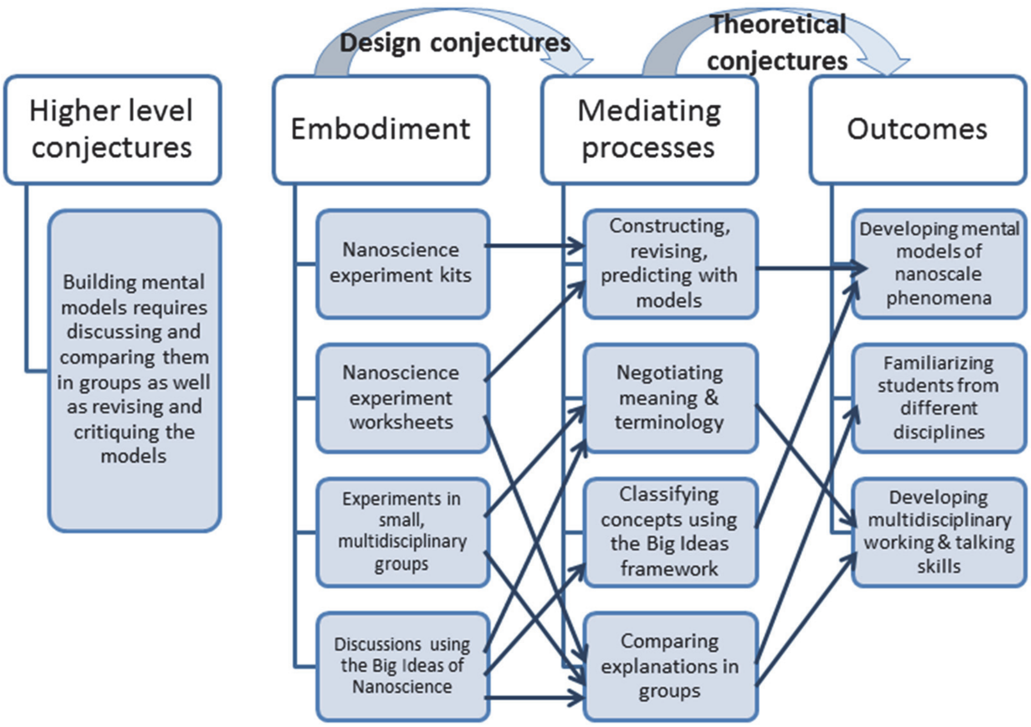


FIGURE 6 Initial conjecture map made during the design phase (2012) of the nanoscience course, reflecting the hopes of measuring course outcomes through expressed models in drawings and writings

5.2 The balanced design for interdisciplinary group work skills

A conjecture map that reflects the design and the outcomes more realistically is drafted in FIGURE 7. It begs the question why the materials were not changed between 2012 and 2013: already in 2012, design choices had included learning goals for much more than just modelling (this should be evident, but not very well expressed, already in FIGURE 6).

The conjecture map shows the presupposed connections between outcomes and embodiments; it allows the designer to track down possible problems in the design. The outcomes are representative of the learning goals expressed in Chapter 3. The theoretical understanding of learning processes is behind the connection between mediating process and outcome; the view of learning in Chapter 4 defines the mediating processes that are proposed to lead to these hoped for outcomes. Finally, the embodiments are designed to fit the context described in Chapter 2, ensuring that the design fits the local requirements for course contents, as well as available laboratories, experts, and the intended audience.

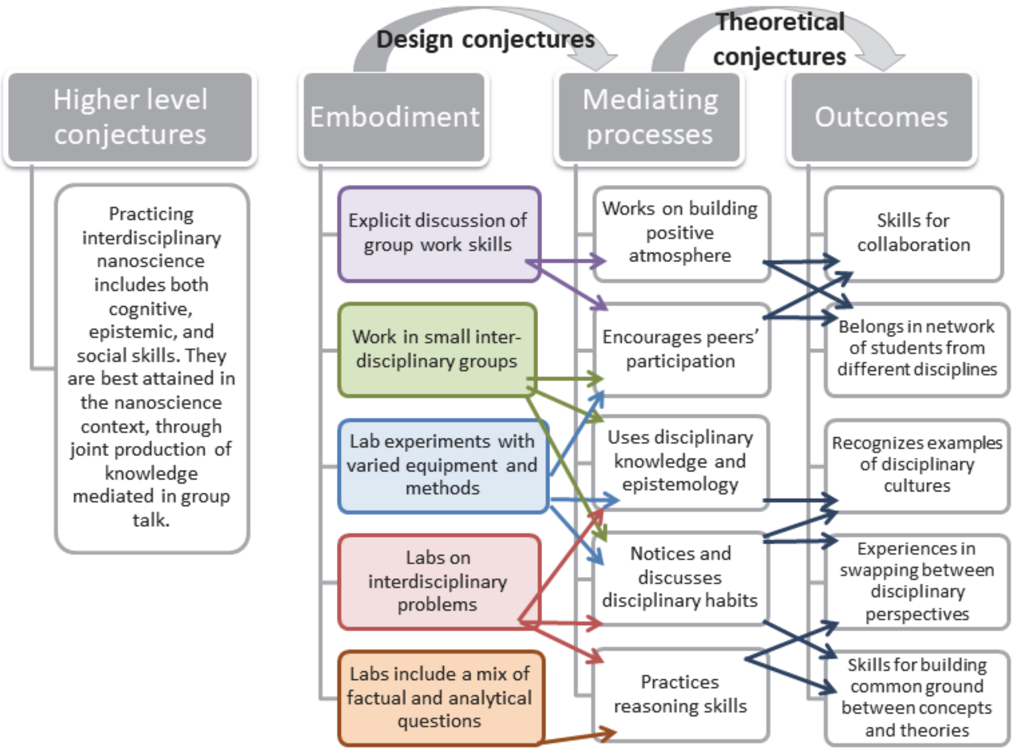


FIGURE 7 A balanced design conjecture map of the course. The embodiments are the designed elements for the course, such as the tangible plans for lab work or structures for lesson group work. The mediating processes are actions of students that are expected to follow from the embodiments. And, the outcomes are beneficial skills or acquirements expected to follow from the actions as expressed in the higher level conjectures.

The beauty of using the conjecture map in the design process is that we are able to find a fault at the right spot: if students are not developing any skills for collaboration (upmost outcome in the map) I can look for whether there is evidence of students working on building a positive atmosphere or encouraging each other. If there is, I conclude having had my theoretical understanding wrong: practising these does not lead to better collaborative skills. Or, should I find that the students do nothing on building a positive atmosphere (upmost mediating process in the map), the designed explicit discussion of group work skills and requirements is not a good design, as it did not lead to the expected actions.

5.3 Overview of the initial design

The course was initially prepared for spring 2012 as a 2-ECTS-course, with three lecture sessions, four laboratory sessions, and three writing tasks (an essay, a summary of a scientific article, and a learning diary). The course ended with an exam, and the students received a fail / pass grade only with a short written feedback on the work they had submitted during the course.

5.3.1 The teacher orientation

As the teacher of the course, I familiarized myself with these models that promote group interdependence (such as think-pair-share and the jigsaw model) and respective listening (the circle of voices). These were possible methods for me to instill trust between group members. I tried to model the openness and trust expected of the students, for example in explaining which areas of the sciences I had very little expertise of, and expressing kudos to students when they offered their knowledge in these areas during the course.

Strober, quoting Lencioni, picks this "vulnerability-based trust" as one of the key qualities required of leading interdisciplinary conversations or collaborations (Strober 2011, p. 128). She also writes about sensitivity to - and ability to bring to light – the different disciplinary cultures of participants (pp. 129-130). I was conscious of this suggestion throughout the course, trying to use opportunities in the laboratory in particular to highlight some cultural differences. As an example, I would explain the differences in handling glassware after it is used in class – at the Chemistry department student laboratory, glassware is almost expected to contain traces of something as the students wash it themselves, but at the Biology student laboratory, the glassware is taken away for wash and autoclave sterilization after students pre-wash it, and it returns on the shelf sterile. So the expectations regarding cleanliness of glassware are different in these labs and have an effect on how people work with them.

5.3.2 The lectures

The lectures were influenced by the ideas from our interview panels and the literature review so that the collaboration and group working got a large share of lecture time. The lectures each had multiple points for student participation and typically following a model that promoted group interdependence. The group explicitly was guided to discuss experiences of group work and from these, decide upon a set of ground rules for good group work. The ground rules were reviewed after the first laboratory sessions as a reminder. This is the topmost item on the Embodiments in FIGURE 7.

In an attempt to fulfil also content learning goals, the students were introduced to the framework of 9 Big Ideas of Nanoscale Science and Engineering (Stevens, Sutherland & Krajcik 2009) through a short lecture by myself. The students listened to a short explanation about each big idea (see TABLE 9) with examples from multiple disciplines when possible.

The Big Ideas were, it was explained to the students, to be used as a checklist for deducing if something was nanoscience, or for explaining someone why a particular phenomenon was nanoscience. The Big Ideas were used in class in combing through mass media texts about nanoscience or nanotechnology findings, and the student groups collected examples of nanoscience and each big idea for a particular theme. The findings from all themes were shared with the whole class.

On the second lecture, I presented a model including a mathematical relation (Bragg's law) for color formation in liquid crystals – this was one of the instances where the mathematical understanding was wrought into course contents, based on the researcher and student panel ideas. This was used as a detailed example of the Big Idea "Structure of matter". Two physics student teachers, as part of their studies at the Department of Teacher Education, also showed a demonstration during the lecture. It was a detailed example about surface-to-volume ratio, using potatoes cut into large or small portions, and sunk into a low concentration solution of hydrogen peroxide. The lecture sessions also included an overview of the research groups working in the nanoscience center (by visiting the center website), and a short guide to skimming through a research article.

The disciplinary habits and perspective-swapping was brought into the lectures through discussing the experiences of studying different disciplines, and examples from researcher interviews about what it might mean that it is not easy to understand someone in another discipline.

TABLE 9 The Big Ideas of Nanoscale Science and Engineering (Stevens, Sutherland & Krajcik 2009) as used on the course

Big Idea of Nanoscale Science and Engineering	Short explanation	Example used in the course materials
Size and Scale	The amount of matter affects its behaviour	The bear has a larger surface-to-volume ratio than a mouse
Forces and Interactions	Dominant forces are different for small objects	Particles in homogenized milk stay equidistant, while the particles in apple juice fall to the bottom of the glass
Self-assembly	With the right ingredients and settings, a system can be expected to self-assemble in a certain manner	DNA origami (calculated design of DNA strands so that they form predestined shapes)
Quantum Phenomena	Some quantum effects are observable, particularly at the small scale	Tunnelling reaction within chlorophyll as basis for photosynthesis
Structure of matter	The organization of atoms in matter affects its qualities	Differences between different allotropes of carbon (diamond, fullerene)
Size-dependent Properties	There are abrupt, qualitative changes in behaviour of matter when scale decreases, often because of surface level processes	Colours are seen in soap bubbles only at a particular thickness range of the bubble wall
Tools & Instrumentation	Development of ideas drives novel tools & vice versa	The Atomic Force Microscope (AFM)
Models & Simulations	The nanoscale cannot be viewed directly	Images of pentacene by AFM are models of the real nanoscale object
Science in Society	The developments in NSE have an effect on the society, and it translates as responsibility	Medicine production and nanoparticle safety

5.3.3 The laboratory work sessions

The laboratory work sessions were built so that the students would work in small interdisciplinary groups of three or four. Since the goal was to have the students get to know the other nano-students better, I varied the groups instead of putting students in stable groups throughout the course. Another reason for this was the mismatch in numbers of students from each discipline; there always were much fewer biology students taking the course than there were chemistry or physics students, and by circulating the students, most students would get at least one opportunity during the course to work in a group with all three disciplines present.

For students, the laboratory days consisted of a lab work at a student laboratory and a related 20-minute tour in the science laboratories. In 2012 the students physically worked in the Biology laboratory and in 2013 the Physical Chemistry laboratory, while their tasks did not change very much. Some equipment was borrowed on both years from the other departments (lasers and magnets from the Physics lab, the electrophoresis equipment and the samples from Cell Biology, and the hot plates with magnetic stirrers as well as small test tubes from Chemistry). Gold colloid preparation chemicals, Ferrofluid and iron filings as well as toy models of Force microscopes were acquired to be used solely on this course.

The laboratory work topics chosen were to represent different topics and methodologies from each of the disciplines as overviewed in TABLE 10.

The electrophoretic separation technique of various DNA lengths was chosen as one topic, and a laboratory work was developed for this topic as a Bachelor's thesis work by Laajala (2013). Laajala paid attention to ensuring understanding of each step of the electrophoretic method in his design of the laboratory and used the discussions with biology PhD students using this method in their research pertaining canine parvovirus in choosing relevant and genuine questions for the laboratory work. He devised a short inquiry part for the laboratory work, where the students would try to decide which of the samples contained the virus.

TABLE 10 The laboratory worksheets and their topics, designed for the nanoscience course.

Informal name	Scientific topic	Development for course
Electrophoresis	DNA and DNA separation techniques based on size	Developed from scratch
Gold Nanoparticles	Nanoparticle synthesis, using color as indicator of particle closeness and/or size	Based on existing learning materials, with major additions.
Force Microscopy	Atomic scale manipulation technique and equipment, understanding principles via analogy to a magnetic force "macroscope"	Based on existing learning materials, with minor changes (narrowing down contents).
Nanoscale Magnetism	Behaviour of magnetic nanoparticles, surface effects in small scale	Based on existing learning materials, with minor changes (narrowing down contents).

The gold nanoparticles were a hot topic at the Nanoscience Center at the time, and a good example of a topic giving rise to interdisciplinary collaborations. They were chosen as the topic of one laboratory experiment. The experiment was built upon the instructions published in Journal of Chemical Education (McFarland et al. 2004), but complimenting the topic with a qualitative introduction to surface plasmons and formation of colors in metals and many other materials. The students were given the original cookbook instructions for the synthesis, but an open task to explain how the synthesis happened with the given chemical ingredients – to explain the aggregation of gold with some hints ("a redox reaction") and why the particles would stop growing, and again to explain why addition of saline solution would change the color of the mixture. The students were encouraged to use two research articles about gold nanoparticle designs, and their measured absorbance and emittance with varying particle distances. This laboratory work came closest to being an inquiry task; the others were more guided, and here perhaps the teacher and TA at least tried to provide guidance and routes for students to explore when they were getting stuck.

Force Microscopy was chosen as the Atomic Force Microscope (AFM) is such an iconic research tool in the nanosciences. It served also to include an example of imaging to bridge into the other nanoscience laboratory course. We had good experiences of teaching the use of AFM through using toy models (as mentioned in section 4.2) and had materials and equipment for this laboratory topic at hand. The tasks for students were to calibrate this toy model device, use it to measure forces between particles that were brought closer and closer together, and to measure across a flat area with magnetic interactions as the third dimension (in analogy for the AFM measuring across an area, where the third dimension was height). For the force microscopy task, some pre-questions were added to relate the toy model to the atomic scale, asking students to remind themselves of the scale of atoms, molecules, and the interactions relevant between atoms or molecules. What was withheld from the existing designs (Planinsic, Lindell & Remskar 2009, Lindell, Anssi & Kähkönen 2013) was the expansion into tapping mode of imaging as well as using several different toy models for the force microscope.

And finally, the Nanoscale Magnetism was chosen because it was a good topic for better understanding the dominant interactions between particles in different scales, and because the learning materials developed for exploration of this topic by Sederberg were very detailed and fit the goals of the course well (Sederberg & Bryan 2010, Sederberg 2012). They encouraged students' own exploration and explanation. The materials were modified to contain a numerical approximation for the relative sizes of iron particles (iron filing compared to nanoscale rust particles in Ferrofluid) and a numerical approximation of the portion of the particle that was "surface" compared to the portion which was "inside". The materials even contained a visual model, created through computational analysis, of the effects of size and surrounding temperature on the magnetization of a particle.

The laboratory worksheets were designed to contain tasks where students explain their thinking or understanding of a topic with both their words and by drawing figures. This was a design choice aligned with the original intention of seeing how students' mental models of nanoscale phenomena developed. The modelling tasks were good for variety in the analytical questions throughout the lab worksheet set. They were balanced with a number of factual questions, defitinions and simpler connection-making, including a few questions directly intended for highlighting differences in vocabularies between disciplines.

The worksheets, in Finnish, are found in the Appendix 1.

5.3.4 Updates into 2013

The class of 2013 experienced the lecture set slightly differently. Based on student feedback in the learning diaries, the demostration on surface to volume ratio was dropped as "too childish". In its place, some extra time was devoted to the mass media news on nanoscience and nanotechnology task, promoting the use of Big Ideas and group interdependence. The third lecture and one writing task were again intertwined, but now it was the students' task to have interviewed a nanoscience researcher and to present their findings about how they had gotten into nanoscience, and what they were doing today (and why they thought it was nanoscience). These presentations took place on the third lecture session.

The laboratory sessions remained almost intact, as the experiences from the first year had been positive – there was no major change explicitly needed – and as the evaluation through students' expressed models and drawings did not work as intended. The second year's data would be added to the first year's on the laboratory work to build a larger dataset and to evaluate the actions of students during their laboratory sessions better.

The changes that took place in the laboratory sessions were: samples used for the Electrophoresis laboratory were changed from parvovirus-carrying DNA into plasmids (fragments of double-stranded DNA) some of the sentences were edited to clarify what a plasmid was. The force microscopy laboratory work was edited to contain an image of an example toy model microscope to help students put theirs together. These changes did not change the nature of the laboratory sessions or even the nature of the related questions. In addition, a TA – a graduate student from Cell and molecular biology - joined the laboratory sessions, to provide examples of interdisciplinary work and discussion also between the teacher and the TA. It made it also easier for students to get help in the lab, as they sometimes had had to wait quite long in the first year with three groups working at the same time on the same tasks.

Later updates and their basis in the findings of the thesis, or other experiences and developments, are recounted in the discussion section 10.7.2.

5.4 The design research and the evaluation phase

As outlined in section 1.4, using Design-based research means analysing evidence and using it to evaluate the design, making changes and re-evaluating in a cyclic process. The Chapters 6-9 of thesis concentrate on the analysis of the designed embodiments and the mediating processes. Of the outcomes, a few can be assessed using the collected data. Others are outside the scope of this data and thesis. The evaluation phase is therefore not completed within this thesis, and the design process here in that sense does not complete an entire cycle, even though the course has continued existing and undergone other more or less cosmetic changes.

The following chapters nevertheless take an analytical look at the designed learning sequences and provide the reader with a new angle to analysing the mediating processes and the design step, as well as offering a detailed look in how students express and handle the border-crossings between disciplines.

6 OUTLINING THE DATA AND METHODS

In this section I introduce the methodologies used to obtain information on the mediating processes as well as outcomes of the design (see FIGURE 6 in section 5.1). It means this chapter is concerned with collecting evidence on whether the expected mediating processes occur in the laboratories and evidence about (or against) students developing interdisciplinary talking or working skills and them become more familiar with one another. The thesis aligns with a pragmatist worldview (Plano Clark & Creswell 2007, p. 27) in that it employs methodologies from both qualitative and quantitative traditions where it makes sense to do so to answer questions relevant to the larger problem – the analysis of the processes taking place during the course. Therefore the methodological choices follow from practical choices rather than aligning with a singular paradigm, while the study certainly leans more on the qualitative side. The data collected is qualitative in nature, but quantitative and qualitative analyses are performed, making the study similar in nature to mixed methods data analyses used in content analysis studies (ibid, p. 16).

The focus of this thesis is the students' work in the Laboratory spaces, in the small interdisciplinary groups. Therefore the embodiments or mediating processes concentrated on the lectures (such might be "discussions using the Big Ideas of Nanoscience" of which there were several instances in the lectures, and one task per lab worksheet) are left out of the picture.

The laboratory experiment worksheets and the students' work in the laboratory are the main interest of this thesis. The possible student groups to follow are numerous and the choices in sampling from the data collected through 2012 and 2013 are explained in section 6.1.

To evaluate the worksheet design – some of which was reused from other sources – requires the questions to be sorted according to some typology; the choice of this classification system is worked out in section 6.2. This classification will allow me to compare the intended laboratory work sessions with one another – if they are balanced or if there are considerable differences in what each lab puts weight on. I can also look at the four labs altogether to see how the course fits to its demands on a whole.

To move further from whether the questions and the design is what was intended – offering students opportunities to practise skills relevant to nanoscience learning – and to find out if this learning is happening, I needed to analyse how the students approach this material. This was done through analysing the student talk during the lab sessions. In sections 6.3 and 6.4, I will explain the choices in transcribing and coding the student talk. From pairing the student discussions with the worksheet questions I had the possibility to compare differences in talk between the different types of questions. This allowed me to make connections between types of questions and resulting talk. I finally used these results to evaluate the design conjectures, and to an extent, the theoretical conjectures.

In the last section 6.5 I will introduce methods from the ethnomethodological model that were used to better understand what role the disciplines and interdisciplinarity have in the students' interactions within these lab work groups. This allowed me to evaluate the outcomes of the course and to confirm or dispute some of the theoretical conjectures.

6.1 Study participants and data collection

6.1.1 Voluntary participation and informed consent

The students were informed before the start of the course that the development of the course calls for research data, and they had the opportunity to become familiar with the research agenda beforehand. The research permit was collected via e-mail in 2012 and through a print permit sheet in 2013; both are available in the Appendix 2. Students were not pressured into taking part in the research, and much care was taken to word the sheets in this manner. As is evident from the permits, the sheets adhere to the APA ethics code where informed consent is considered; the items on the definitive list (Smith 2003) include

- "The purpose of the research, expected duration and procedures.
- Participants' rights to decline to participate and to withdraw from the research once it has started, as well as the anticipated consequences of doing so.
- Reasonably foreseeable factors that may influence their willingness to participate, such as potential risks, discomfort or adverse effects.
- Any prospective research benefits.
- Limits of confidentiality, such as data coding, disposal, sharing and archiving, and when confidentiality must be broken.
- Incentives for participation.
- Who participants can contact with questions."

The list contents were met in all other respects except for the potential risks, discomfort or adverse effects. After discussion with thesis supervisors such effects could not be foreseen or were so particular that they missed the "reasonably foreseeable" descriptor – such as the possible discomfort in knowing someone listened to one's taped discussion.

In 2012, the students received an informatory e-mail before the beginning of the course, containing the research permit sheet. They were asked to send their permission or opt-out message via e-mail. 2 out of 17 students in this year wished to not participate in the research. One announced this before the course and the other withdrew the permission during the course. The groups that these students worked in were recorded until the end of the course, just as the others, to ensure they did not stand out in the groups. The groups schedules were not altered to put the non-participating students in the same group, so that they also came across new faces, as was an intended social goal of the course. Any data from these recordings was not listened to or used in analysis. Because of this, from the 4 x 5 lab work recordings, only 13 were available for analysis.

In 2013, the research was introduced to students in a face-to-face information session before the official start of the course. It consisted of a short verbal explanation of what was collected and what the data was used for. The students received also written research permit sheets and returned pieces with their signature during this meeting. A few students who could not attend this meeting were then reached via e-mail and asked to give their informed consent via e-mail, in the same way as the group of 2012. All 24 students enrolled in the course participated in the research this year.

Six students did not complete the course in 2013 (18 reached completion). The students' data from the lab work sessions they attended before dropping out is used in the analysis. These students did not retract their consent for research.

6.1.2 Choosing the student groups

Student groups whose talk was analysed were chosen to represent different setups – group sizes, group compositions and teaching years (2012 and 2013). These groups are listed in TABLE 11.

The chosen groups represent each laboratory work topic as well as both years of data collection. There are different compositions of student major disciplines, and the group sizes (3 and 4) are representative.

Deviant cases that are not covered by this sample would include student groups which consisted of students all of the same major, or smaller or larger groups. There were a few instances in these years where – because of absences – there were only two or even five students in one group. Because of the same reason, once or twice a group would only have students from Physics or Chemistry departments. These were not the designed solutions, and it does not make sense to evaluate the course design on these deviant cases.

However, it could be interesting to compare the discussions in a group that only consisted of a single major, and one group where this happened (F12-g5) was chosen into the sample for possible comparisons.

TABLE 11 Analyzed student group conversations from the laboratory work sessions

Recorded group	Date recorded	Group size	Major composition	Laboratory work
E12-g1	April 23, 2012	3	2 x Physics 1 x Chemistry	Electrophoresis
E12-g2	April 23, 2012	3	2 x Physics 1 x Chemistry	Electrophoresis
E13-g1	April 4, 2013	3	2 x Physics 1 x Chemistry	Electrophoresis
F12-g1	April 24, 2012	3	2 x Chemistry 1 x Biology	Force Microscopy
F12-g4	April 24, 2012	3	2 x Physics 1 x Chemistry	Force Microscopy
F12-g5	April 24, 2012	3	3 x Physics	Force Microscopy
F13-g2	April 5, 2013	3	2 x Physics 1 x Chemistry	Force Microscopy
N12-g1	April 25, 2012	4	3 x Physics 1 x Chemistry	Gold Nanoparticles
N12-g3	April 25, 2012	3	2 x Chemistry 1 x Biology	Gold Nanoparticles
N13-g1	April 12, 2013	4	2 x Chemistry 2 x Physics	Gold Nanoparticles
M12-g2	April 26, 2012	3	1 x Biology 1 x Chemistry 1 x Physics	Magnetism at Nanoscale
M12-g4	April 26, 2012	3	2 x Physics 1 x Chemistry	Magnetism at Nanoscale
M13-g2	April 18, 2013	4	2 x Chemistry 1 x Biology 1 x Physics	Magnetism at Nanoscale
M13-g4	April 19, 2013	4	3 x Physics 1 x Chemistry	Magnetism at Nanoscale

6.1.3 Other data collected

The data that was collected, but not used in this main strand of analysis, include

- video recordings of the lectures
- video recordings of the laboratory work
- students' pre and post tests in the course
- copies of students' filled out worksheets
- learning diaries
- four clarifying interviews with selected students on the models they used in their pre-test or laboratory worksheet and on this course structure

These data were collected through both 2012 and 2013 courses. They offer a possibility for triangulation, especially the students' learning diaries and the interviews. Once the analysis findings are established, I have the opportunity to bounce these findings off of these two sources where students express their opinions about the course contents and in some occasions, interdisciplinary manner of studying. Reasons for not directly using these interviews and learning diaries in analysis are to keep this portion of data for establishing validity through the constant comparative method (e.g. Silverman 2001, p. 238-239) but also because of their large variance in format and content.

6.2 Laboratory worksheet coding

The goal in classifying the different questions in the worksheets is firstly to evaluate the balance or diversity of different types of questions amongst the worksheets. The first step is to decide on which aspects of the questions are interesting – and well aligned with the mediating concepts - to use for classification. Once this coding scheme is decided upon, one can use the scheme to collect evidence on whether a question type would elicit a particular kind of talk, which is explored in section 6.4.

The classification, from hereon referred to as coding (as the coding was realized through Codes in the Atlas.TI program's toolset), and the ways to ensure its reliability, are the content of this section.

6.2.1 Finding a suitable coding scheme

Different typologies were considered for this purpose, most notably the TIMSS (Trends in International Mathematics and Science Study) Science cognitive domains for Eighth Grade (Jones, L. R., Wheeler & Centurino 2013) and the TIMSS Advanced Physics cognitive domains for Secondary school (Jones, L. R., Wheeler & Centurino 2014). These domains and their subclasses of task or item types are very similar. They differ by three items in the domain of Applying knowledge – only the Science task types include the "Compare / Contrast / Classify" and "Relate" task types, and only the Physics task types includes the "Find solutions" type. This tilted the scale towards choosing the Science task types. Since "Using models" naturally includes the use of equations and formulae, as particular types of models for physical or chemical relationships, such tasks were still recognized by choosing the Science task types. The cognitive tasks of comparing and classifying were seen as an important part of chemical and biological skillsets (see e.g. Nehm 2010), and it was therefore necessary to keep them on board.
The chosen task types, their descriptions, and examples of questions coded as this task type, are shown in TABLE 12

TABLE 12 TIMSS Science question types, from Jones, Wheeler, and Centurino (2013), supplemented with examples from the worksheets from laboratory sessions

Cognitive domain	Question type / ability	Description	Example question
Knowing	Recall/ Recognize	Identify or state facts, relationships, and concepts; identify the characteristics or properties of specific organisms, materials, and processes; identify the appropriate uses for scientific equipment and procedures; and recognize and use scientific vocabulary, symbols, abbreviations, units, and scales.	M13 q3b "Recall or find out from sources/teachers what is meant by the following terms: a) magnetic domain b) ferromagnetic c) diamagnetic d) paramagnetic e) magnetic hysteresis."
	Describe	Describe or identify descriptions of properties, structures, and functions of organisms and materials, and relationships among organisms, materials, and processes and phenomena.	F12 q14 "What does the sample look like to you?"
	Provide Examples	Provide or identify examples of organisms, materials, and processes that possess certain specified characteristics; and clarify statements of facts or concepts with appropriate examples.	E12 q8 "Which factors affect the movement of DNA in electrophoresis?"
Applying	Compare/ Contrast/ Classify	Identify or describe similarities and differences between groups of organisms, materials, or processes; and distinguish, classify, or sort individual objects, materials, organisms, and process based on given characteristic and properties.	M12 q13 "Using magnets and compasses, find two differences between mixture of iron filings and oil, and ferrofluid. Which differences did you spot?"
	Relate	Relate knowledge of an underlying science concept to an observed or inferred property, behavior, or use of objects, organisms, or materials.	N12 q10 "What kinds of forces are there between the particles in solution?"
	Use Models	Use a diagram or other model to demonstrate knowledge of science concepts, to illustrate a process cycle relationship, or system, or to find solutions to science problems	F12 q9 "Based on the graph, why can you describe the behaviour of the cantilever using an equation for springs?"

TABLE 12 (Continued)

Cognitive domain	Question type / ability	Description	Example question
Applying	Interpret Information	Use knowledge of science concepts to interpret relevant textual, tabular, pictorial, and graphical information.	M12 q20 "Explore the simulation [of magnetic particles]. Fill in possible blanks in previous questions."
	Explain	Provide or identify an explanation for an observation or a natural phenomenon using a science concept or principle.	E12 q13 "Why are some of the lines [in the print photo of the gel in UV light] darker than others?"
Reasoning	Analyze	Identify the elements of a scientific problem and use relevant information, concepts, relationships, and data patterns to answer questions and solve problems.	E12 q5 "How does the % concentration of agarose in the gel effect on the movement of particles through gel?"
	Synthesize	Answer questions that require consideration of a number of different factors or related concepts.	E12 q10 "How does electrophoresis separate strands of different lengths?"
	Formulate Questions/ Hypothesize/ Predict	Formulate questions that can be answered by investigation and predict results of an investigation given information about the design; formulate testable assumptions based on conceptual understanding and knowledge from experience, observation, and/or analysis of scientific information; and use evidence and conceptual understanding to make predictions about the effects of changes in biological or physical conditions.	N12 q7 "The models below show structures of the compounds. Predict what will happen to the molecules in boiling water and what happens when the solutions are combined. Hint: How would a redox reaction produce gold nanoparticles from these?"
	Design Investigations	Plan investigations or procedures appropriate for answering scientific questions or testing hypotheses; and describe or recognize the characteristics of well-designed investigations in terms of variables to be measured and controlled and cause-and-effect relationships	M12 q2 "How would you study the magnetic field of your straw magnet?"
	Evaluate	Evaluate alternative explanations; weigh advantages and disadvantages to make decisions about alternative processes and materials; and evaluate results of investigations with respect to sufficiency of data to support conclusions.	E12 q12 "How accurately do you think electrophoresis can separate base pairs?"

TABLE 12 (continued)

Cognitive domain	Question type / ability	Description	Example question
Reasoning	Draw Conclusions	Make valid inferences based on observations, evidence, and/or understanding of science concepts; and draw appropriate conclusions that address questions or hypotheses, and demonstrate understanding of cause and effect.	F12 q16b "[What kinds of problems did you encounter during your measurement?] Underline the problems you expect to apply to measuring with an actual Atomic Force Microscope."
	Generalize	Make general conclusions that go beyond the experimental or given conditions; apply conclusions to new situations.	M12 q6 "Expand on your previous answer. What happens to a substance when it is magnetized?"
	Justify	Use evidence and science understanding to support the reasonableness of explanations, solutions to problems, and conclusions from investigations	(none)

Other classification schemes were considered alongside the TIMSS typology. While they had certain merits in comparison with the TIMSS typologies, such as being developed with Higher Education in mind, they fell short on other levels. A short description of each and the reason why it was not seen as suited for this research is shortly laid out in TABLE 13.

Another possibility for typifying the worksheet questions would have been through open coding and self-classifying the different cognitive demands of different tasks. Seeing that such typologies were readily available, well established, and thoroughly tested (such as the TIMSS), this option was not pursued.

TABLE 13 Task type classification schemes that were considered as schemes for coding, and reasons for not choosing them

Source	Categories	Reasons why not chosen
End-of-chapter problem types (Knight 2004)	Conceptual, Estimation, Graphical, Algebraic, Biomedical, Context Rich, Jeopardy	Does not address cognitive domains; too close focus on physics
Novel task types in engineering education (Demel, Freuler & Harper 2005)	Experiments, Problem posing, Ranking tasks, WRONG problems, or Design & Build	Describes settings rather than the demands of a problem; most task types not found in the worksheets used
High-level task types for Science and Engineering (Felder & Brent 2004)	Predicting outcomes, Interpreting and modeling physical phenomena, Generating ideas and brainstorming, Identifying problems and troubleshooting, Formulating procedures for solving complex problems, Formulating problems, Making judgments and decisions and justifying them.	Does not allow categorization of lower level tasks, which were proficient in worksheets used; otherwise overlaps TIMMS task types
Next Generation Science Standards Dimension 1 – Scientific and Engineering practises K-12 (NGSS Lead States 2013, p.41)	Asking questions and defining problems, Developing and using models, Planning and carrying out investigations, Analyzing and interpreting data, Using mathematics and computational thinking, Constructing explanations and designing solutions, Engaging in argument from evidence, and Obtaining, evaluating, and communicating information	Does not adequately address differences between lower level cognitive tasks, i.e. too broad
Conceptual-Reasoning-Mode (CRM) model of reasoning (Anderson et al. 2013)	Abilities to use a representation (e.g. decoding symbolic language, evaluating the limitations, using a representation to solve a problem, constructing a representation, …) and abilities to use a concept (e.g. memorizing related knowledge, transferring knowledge and applying the concept to novel problems, reasoning analogically about the concept, …)	Describes abilities but doesn't link to demands of a question requiring these abilities in many cases

6.2.2 Assessing reliability in Question type coding

The coding scheme, once chosen, could be applied by other coders and checked for agreement amongst coders. The reliability with which the coders apply the coding scheme can describe the reliability of appointing these codes altogether. Are the worksheet questions described adequately by this set of codes, and is there considerable confusion about which code best represents each question?

Initially, the number of questions was 68 for worksheets used in year 2012. The reliability of the question type coding could be assessed by taking a sample of the questions through random selection and having reliability coders assign codes to these questions. Two reliability coders – PhD students in Science Education, who were not familiar with the TIMSS question type manual or the laboratory worksheets before - were asked to code a portion of the questions.

The reliability of question type coding was decided to be measured with two reliability coders and calculating Fleiss' kappa and the average pairwise Cohen's kappa, designed to measure inter-coder agreement for nominal data assigned to cases (i.e. the codes assigned for questions).

Fleiss' kappa describes the extent by which the observed amount of agreement among coders exceeds the situation where all coders assign their codes randomly. Cohen's kappa expresses the same between two coders; the average pairwise Cohen's kappa is the average from all coder pairs' Cohen's kappas; here, there are three pairs. For these measures, considered conservative, a rating of 0.80 or higher is thought to be acceptable (Lombard, Snyder - Duch & Bracken 2002).

The measures for Fleiss' kappa and Cohen's kappas are calculated with ReCal3, an online tool to compute intercoder agreement for three or more coders (Freelon 2010).

6.3 Transcriptions of laboratory session discussions

To be able to tell if we reach any of the intended student actions – the mediating processes in FIGURE 7, we must transcribe the talk to make it available for coding – tagging the relevant parts of the transcript with the codes for actions we are interested in most.

The first decision to make is the amount of detail in coding (Lapadat 2000). The purpose of the coding here is to analyse the content of the student talk: which question they are talking about, and a little further, how are they addressing the problems: they are using their group mates' responses, offering their own knowledge, making sense of what is being asked, or reformulating what they said so their peers could better follow their thoughts – and maybe something else. For transcribing purposes this means I am interested mainly in what they're saying and just a little interested in how they're saying it. To refrain from coding the whole set of lab session tapes to minute detail, it is important to decide up ahead what is the necessary quality of transcription for this purpose. A rough transcript is made of the complete mass of data, using word to word transcription.

Using this level of transcription, I can compare the codes for features in the discussion with the codes for each type of question and look for patterns: is this topic always addressed in the same manner, or does this type of question elicit more structured, argumentative answers than another? This way I will be able to answer my research question on how and which learning goals the students are meeting, and whether the design conjectures actually lead to productive discussion promoting interdisciplinary skill acquisition.

6.3.1 Transcribing for coding: Rough transcription

Conversations at Labwork sessions were transcribed by the author, apart from three files which were partially transcribed by a research assistant . The transcipts were made using the timestamp property in Atlas.TI. The taped discussion from each lab session was uploaded and a document set up to link with this tape. This allows the user to set timestamps amidst the text and to be able to re-listen to a span of discussion starting at the timestamp.

Each session was transcribed from the beginning of the recording, until the students had a final discussion to go through their answers with the teacher or TA. The students' interaction among each other was the main interest in the taped discussions, although when the teacher or TA was talking with the group, their input was transcribed as well. The timespan of one lab session was, on average, two and a half hours.

The rough transcript containing information of turns of talk, the words students used, and the audible manifestations of their actions (tinkering, laughing, yawning, tapping with pen), was made of the 14 chosen laboratory group sessions. The speaker was only identified when it was very clear, and at other times it was only marked when the speaker changed (i.e. the changes of turns). This goes against the convention, but was a conscious choice to limit the workload and align with the purpose (see Lapadat 2000). The choice was made since the information about an individual was not part of the following analysis, and a person was not tracked through the discussion or several group work sessions. The contents of the discussions shared by the whole group was the main point.

This rough transcript was deemed sufficient for the coding purposes, which are at the level of topic, structure and content of the discussion and barely scrape on the interaction between students. The nonverbal ques or in depth information of students tones would not affect these codes to be used, and neither would the definite identification of each speaker.

6.3.1.1 Rough transcript markings and conventions

The rough transcript was made in Finnish and the examples or excerpts from the transcripts used in this thesis are translated into English. The Finnish is not shown alongside the translations of rough transcripts. The translation must be sensitive to the details and nuances of the original language and speaker, but also adhere to the style and tones of similar conversations in English (Hepburn & Bolden 2013). An example of translation is shown below.

TABLE 14 Example of translation in rough transcripts. Excerpt is from E12-g1 (23 minutes into the session)

Speaker	Finnish	English (translated)
S1	Onks se vieläkään lämmenny?	Has it heated up yet?
S2	No on se kirkkaampaa kun se oli äsken, mutta ei se nyt vielä ihan.	Well it's clearer than before but it's not quite there yet.
S1	Nyt on!	It's done!
S2	Kokonaan kirkasta ole.	It ain't clear all the way.
S1	No, nyt se on taas samee.	Oh, now it went back to cloudy.
	(naurua)	(all laughing)
S1	Nih. Kiittäkää mun sekotustaitoja.	Yah. Thanks to my mixing skills.

Excerpts include information of the speaker as S1 (Student 1), S2, S3 etc. If speaker information was not present in the original transcribed piece, it was checked for the short excerpt (e.g. whether there were two or three participants within the excerpt). The numbering starts from the first line and it may differ if another excerpt is taken from the same session – so S1 may not be the same student in two different excerpts.

The other speakers are denoted as T for teacher; TA for teaching assistant, and V for the occasional visitor to the lab.

6.3.1.2 Rough transcription quality and possible problems

On some tapes, two groups had sat so close to one another that it was sometimes very difficult to keep track of which group was talking. There were two instances of these settings in the sessions chosen for this study. It was still possible to follow the discussion and to transcribe. These tapes were not left out of the dataset, based on the following reasoning: Firstly, this was also the (noisy, crowded) environment that the students worked in during that session, and some features of this environment might be lost if only the cleanest tapes were used. Secondly, the taped discussions reveal that the groups positioned very close to one another also worked together to some extent – they checked back with the other group to compare results – in a sense, they used the other group as an extension of theirs. So all of the tapes chosen were transcribed and coded, even though the two tapes contained considerable amounts of talk from the adjacent group.

6.4 Coding and interlinking the discussions

The aim of this part is to offer insight into whether certain kinds of questions are related to certain kinds of talk. To be able to classify "kinds" of talk, one has to set upon a scheme for looking at the data. In Mercer's overview of several oft-used methods or methodologies for studying classroom talk (2010) he covers both quantitative and qualitative approaches.

Suonio (2012) explored the linkage in the discussions from these laboratory sessions between students co-constructing for a model or explanation and the variety of science terminology that they used in their discussion. She found a link between using purposeful, more limited terminology and constructing a model of the Gold Nanoparticle synthesis. When the group explored various science terms and tried to apply them in the situation, they were less likely to complete a model that represented the situation.

Here the purpose is to look at linkage between two more general levels: the discussion about a type of task – the cognitive demands of the problem (as outlined in the TIMSS typology of TABLE 12) and the kinds of interactions between students, which are the topic of the following sections.

6.4.1 Coding talk in relation to a worksheet question

This step of the analysis was to be made without a coding manual. Content-driven recognition of topics that were relevant to answering a certain question, paired with the knowledge of the order of questions in the worksheet, was used to determine which turns of talk belonged to a certain question.

The talk could also be related to carrying out a procedure outlined in the worksheet, in which case it was coded as "Procedure" talk. Sometimes the students spoke of something else entirely, such as lunch break or weekend plans, and these were coded as "unrelated".

6.4.2 Coding talk per dimension of Interdisciplinary group talk

This section concerns the formation of a coding scheme that informs me about the kind of talk and interaction that is aligned with the outcomes of the course.

The grounds for the coding scheme are from section 4.3, where three sources were consulted on the kinds of interactions that were productive for learning (see TABLE 8). Previously, I outlined the outcomes of the course through introducing them in the form of a conjecture map in FIGURE 7. Within the map, the mediating processes are in particular what I am after at this point. Thickening the descriptions in the conjecture map with ideas both from TABLE 8 as well as TABLE 6, I have put together the following coding scheme to respond to the question, "Do the students take part in group work that supports them in learning skills relevant to doing nanoscience?"

The original idea was to code separately for supportive interaction and invitations to participate in the discussion ("Peer") and affective, personal level familiarity ("Affection"), and to consider sub-codes or sub-categories within these types of interaction. This coding scheme is shown in TABLE 15.

TABLE 15 Dimensions of Interdisciplinary group talk, stemming from talk that support learning goals of the course, categorized into a coding scheme

Code	Description of what the talk is like	Initial sub-codes
Peer	Asks peers for contribution and encourages participation. Uses a peer contribution in one's own turn, is open to using other members ideas.	Encourages Uses peer contribution
Affect	There is warm laughter. Students are building a positive athmosphere. Stories and anecdotes are shared, increasing feelings of trust and belonging.	Shares story Laughs
Reasoning	Students elaborate on or clarify their reasoning. They use abstraction techniques to aid thinking. The students form arguments about an issue addressed, explicitly including claims and evidence.	Elaborates Forms argument Uses abstraction technique
Knowledge	Students offer discipline-relevant facts into the conversation. The students notice different validity protocols in discipline, discussing the validity of a result or a choice. Negotiations on choice of point of view in the situation, disciplinary or otherwise.	Negotiates point of view Negotiates validity Offers fact

This coding was applied to a large part of the collected data, but this part of the analysis was lost because of losing files in a system update (See Appendix 3). Redoing this part of coding made me suspect that it was difficult to make these distinctions reliably. After coding the first discussions and inviting the reliability coder – one of the thesis supervisors - to try out the coding scheme, it was decided to lose some of the detail in exchange for better validity and reliability; the subcodes were not considered. Another change into the coding scheme was made in combining the Peer and Affect codes. They were merged into the "Peer" code that signals positive interaction with group members; this makes sense, since both interaction types were ways of relating with one's peers and enhancing collaboration – the ability to support and use peer help in solving problems, but also building relations that go beyond a course, a kick-start in networking.

So in the end, the coding is aligned with the three skillsets in doing interdisciplinary science: the "soft" interpersonal skills in collaboration ("Peer"), managing and switching between the knowledge and epistemology of all relevant disciplines ("Knowledge"), and the ability to reason and explain one's thinking, all precursors to critical thinking abilities ("Reasoning") – seen as the prerequisite for building the mediating theory-constructing skills expressed in section 3.1.4.

6.4.3 Coding reliability for both types of discussion coding

The coding agreement could be looked at from two different perspectives:

- comparing each turn of talk, if it was coded with the same code(s) (or no code, if none applied)

- comparing each recognized relevant span of talk, if the acknowledged discussion was coded with the same code(s)

The second view is elaborated as follows: One discussion can be a span of turns that is marked with different codes by the coders or a span within non-attributed talk that is recognized only by one coder. If there is a span of agreed upon codes next to a span of coded and non-related talk, the widest attributed span for this code is recognized as one discussion all relating to the same code. The overlapping span may be at the beginning, the end, or the middle of the discussion; or the discussion may have "holes" not attributed to a question by the other coder within.

For the codes related to worksheets, both measures could be used. For codes related to the productive talk / learning goals of the course, it was decided that coding turn by turn would not make a difference to the goals in coding, and the turn-by-turn reliability of coding was not desirable. The productive talk and their overlap with worksheet questions would be evident as long as the spans of talk that matched a code were similarly coded by myself and another coder. The possible discrepancies are assumed to happen at the opening and closing turns (this assumption is confirmed within the turn-by-turn inspection of question-related talk in 8.1.1), such as exclamations ("hey!") or agreements ("mmm"), and these would not be meaningful instances of question-related talk either. So missing out some of the "fringes" would not be harmful to the reliability of the findings.

The reliability check of pairing talk per worksheet questions was split into two parts; firstly, the reliability of locating talk related or unrelated to the questions, and the reliability of assigning these spans of discussion to a particular question in the worksheet.

The reliability coder, a PhD student in biosciences, was invited to assign the worksheet codes to the spans of discussion she felt were related to them. She did not have a particular coding manual other than the worksheet questions for this task. She was chosen as she shared a similar background as the author – classroom experience from this course - for recognizing the kind of talk related to a certain question.

The reliability check of coding with features of productive talk was done with one of the thesis supervisors, who promised to code a randomly chosen lab transcript with the initial version of these productive talk type categories.

The reliability and effect of any adjustments made in the coding schemes or practises were quantified through calculating Cohen's kappa, which describes the extent by which the observed amount of agreement among coders exceeds the situation where all coders assign their codes randomly. This measure was calculated with ReCal2, an online tool to compute intercoder agreement for two coders (Freelon 2010).

6.4.4 Connecting between talk features and the question types: the c-coefficient

One of the goals of this study is to better understand how to build a laboratory exercise that supports students in learning in an interdisciplinary group and environment. The building blocks of such lab work are the questions guiding students through the exercise as well as the procedure and directions itself. How could we tell if the students are learning relevant skills? At a minimum, we can look at their engagement in interactions that encompass these skills; if they are building a good atmosphere to work in as a group (the Peer talk type), if they are using their reasoning and explanation skills (Argument talk type), or if they are using their disciplinary background knowledge and managing the different areas of knowledge or the points of view to a problem (Knowledge talk type). It's possible that these talk types occur more on some questions than others.

It's certain that these connections are not rock-solid. The differences in group compositions, the mood students are in for the day, the match between group members background knowledge and the one asked for in the task all play parts in their ability and motivation to partake in the discussion. Therefore the exploration undertaken in this thesis is of qualitative nature rather than finding quantitative correlations. The discovered connections between talk and question can be strengthened by reasoning about the task structure or content, as well as through a closer look at the discussions students are having that give ground to these connections.

There are several instances of each talk type in the discussions, and several instances of most question types in the worksheets and, consequently, in the discussions. To narrow down to interesting connections, the use of a quantitative aid is warranted to find seeming connections and to zoom in to those spots. A code co-occurrence tool in the Atlas.TI program allows one to look at the correlation coefficient, "c-coefficient", between two codes (Friese 2014, p. 189-190). Here it is used to look at the mass of transcribed discussions and to identify co-occurrences between codes describing the question type students are answering, and the talk types that are present in their discussion.

The C-coefficient for codes "a" and "b" is calculated as

$$C_{ab} = \frac{n_{ab}}{n_a + n_b - n_{ab}}$$

where n denotes the number of occurrences of the codes: n_{ab} is the number of co-occurrences of the two codes, and n_a the total number of occurrences of code "a". It follows that the C-coefficient is zero if the codes never co-occur and one if they co-occur every time. Otherwise the value is between zero and one; the closer to one, the more often these codes appear together, and these are the code pairs of interest.

A closer look will be taken at the code pairs that have highest c-coefficients overall, but also at other outliers such as the cases where a specific question type co-occurs mainly with just one talk type or a question type co-occurs evenly with all talk types.

In addition, the same tool is used to explore the talk types co-occurring with the “Procedure” code (talk related to working through a procedure rather than to answer a worksheet question). The co-occurrence of talk where specific disciplines are mentioned and the different question types can be explored in a similar manner. Apart from the questions and lab procedures, the students engaged in some talk related to the course or course companions (“What was your major subject again?”) or entirely unrelated topics (“So I’m going to take the train to Helsinki this afternoon”). The co-occurrence of productive talk among these topics is not further studied. The findings from this preliminary analysis are presented in section 8.3.

6.5 Ethnomethodology and Conversation Analysis: Taking a closer look at the group conversations

The aim of Conversation Analysis (CA) is to reveal the organized reasoning procedures that inform the production of naturally occurring talk (Hutchby & Wooffitt 2008, p. 3). The participants in a conversation are mutually orienting to achieve orderly and meaningful communication. The CA seeks to make these procedures explicit by analytically examining the structures of conversations, such as the sequential organization of talk (turn-taking). The structures of conversation are features of the situated interaction that is meaningful to the participants, in that they orient their actions and responses with regard to such structures talk (Hutchby & Wooffitt 2008, p. 5).

What conversation analysis can bring to this study is to explore how the participants of group discussions react to the presence of several disciplines. Do they show themselves to be oriented to the phenomenon of interdisciplinarity (or disciplinarity) in their interactions, and if, in what ways? The presupposition that interdisciplinarity must show in the conversations or assumptions on how it should affect collaboration (which might be influenced by previous studies outlined in section 3.1) should be put aside for the analysis. The position taken by conversation analysts is that the “relevance of any analytic category needs to be shown to be relevant for members, or participants in interaction” (Hutchby & Wooffitt 2008, p. 208). Findings that show the participants actions taking the disciplines into account can of course be compared and contrasted with literature on comparative situations; for example, the reports of graduate students’ experiences of conducting research in interdisciplinary settings (Chari 2014).

6.5.1 Overview of the methodological basis

So CA aims to make explicit the rules of talk speakers orient to, either through studying single cases or collections of talk (Markee 2008, p. 26). The analysis is not developed through quantitative, frequency-oriented data; the data and evidence is always the participants' orientation to the structure of conversation. Any claims made by the analyst should be based on similarities to established CA findings in other studies, or strengthened by showing that the structure identified by the analyst applies through different types of cases, throughout the data comprehensively (Silverman 2001, p. 240).

To give the reader an idea of the conducting of CA analysis, I am replicating the "prescriptions" given by Silverman (Silverman 2001, p. 177) to simplify and demystify the analysis:

- Always try to identify sequences of related talk.
- Try to examine how speakers take on certain roles or identities through their talk (e.g. questioner/answerer, client/professional)
- Look for particular outcomes in the talk (e.g. a request for clarification, a repair, laughter) and work backwards to trace the trajectory through which a particular outcome was produced.

These directions describe working with an excerpt of a transcript well. The level of detail in the transcript is higher than in a script for a play, but it is laid out similarly to keep track of who speaks and when. In addition, the transcript uses specific symbols to denote the *how* things are said (more about transcription in section 6.5.3).

Typically CA is applied in freely conducted conversations; there are studies set in more institutional settings such as courtrooms or interviews. Since in this thesis I am limiting my analysis to conversations amongst the students – to find out whether and how the disciplines are meaningful structurers of conversation for them – I am mainly concentrating on conversations that do not follow an institutional structure. The talk still often contains indicators of this social setting and external structure, for example, when the students read aloud texts from their worksheets (which is not a regular practise in everyday conversation) (Hutchby & Wooffitt 2008, p. 140).

6.5.2 Categorization and positioning

Positioning theory is a possible way of looking at the dynamic aspects of encounters; while "roles" could be seen as static qualities assigned to participants, the "positions" could vary through the encounter, established through use of language. Davies and Harré (1990) use the concept in describing the self through relations to others. Hirvonen (2016) makes use of positioning in small-group interactions, where positioning was connected to the task-level of group behaviour. He suggests that task-related positioning is particularly study-worthy in small-group interactions. While positioning theory stems from the critical discourse analytic tradition (CDA) and linguistic analysis, its fit into CA has been argued e.g. by Korobov (2001) and Day and Kjaerbeck (2013). The tensions between the traditions come from their different appreciation of context in shaping the conversations observed; the CDA paints context in terms of larger entities in the participants' social or historical reality and puts the negotiation of power dynamics amongst the participants in focus. Conversation Analysis treats context in a radically more local way, in terms of how it is presented by the participants of the conversation: the context of the previous turns of talk (Korobov 2001).

Korobov divides positioning into three types, and presents the one in line with CA traditions as the construction of characters and speakers (such as "us" or "they" distinctions) or speaking of them as active agents (or passive recipients). Day and Kjaerbeck make reference to the device of Membership Categorization (e.g. Hutchby & Wooffitt 2008, p. 35)– the categories we use explicitly when referring to or describing people or ourselves - and see positioning theory in the same style; focusing on descriptive rather than sequential details in the conversation, and especially on the relations between categories or the more dynamic positions (2013, p. 21). They quote Antaki and Widdicombe's list of five crucial aspects in ethnomethodology for studying identity:

- For a person to 'have an identity' — whether he or she is the person speaking, being spoken to, or being spoken about — is to be cast into a category with associated characteristics or features.
- Such casting is indexical and occasioned.
- It makes relevant the identity to the interactional business going on.
- The force of 'having an identity' is in its consequentiality in the interaction.
- All this is visible in people's exploitation of the structures of conversation.

These categories and identities are used in the analysis to pick out instances where such categorization takes place based on disciplines; what does it do to the interaction, how or when does the notion of a discipline enter the conversation, and how do the conversants use the categorization?

A fascinating option for further studies with this data would be to look at the power dynamics amongst the members on the course – both teachers and students – and to study the differences in interdisciplinary backgrounds and futures. A particularly interesting research direction would be to follow up with the same people at a later time. But this does not play into the focus of this study.

6.5.3 Transcibing for Conversation Analysis: Jefferson transcription system

A more in-depth coding was then undertaken for the closely analysed pieces that were chosen to better understand the mentions of disciplines or interdisciplinarity in student and teacher talk during the course. The pieces were chosen on basis of the coding as later detailed in chapter 8.4. There, the transcription protocol used was the Jefferson transcription system (Jefferson 2004) by adapting to the same symbols. The transcript symbols used are available in Appendix 4.

The precision level in transcription is chosen to include the tones and some of the pronunciational particulars (Jefferson 2004) such as dialects or mispronouncing a word. The finest details of pronunciation, for example the silent letters going pronounced or unpronounced or the hardness/softness of consonants – especially as the Finnish language does not utilize many of these details in meaning-making – are not transcribed. The system used in this thesis uses the Jefferson transcription system apart from these particulars.

The reliability of transcripts used in conversation analysis is not endangered by surrounding sound climates. The chosen conversations were taken from tapes which were clear, excluding the aforementioned tapes with lots of talk from the adjacent group intervening the discussions. To further improve reliability, a group data analysis session could be held to listen through the audiotapes and look at the transcripts with researchers experienced in CA methodologies.

7 ANALYSING THE WORKSHEETS

7.1 Worksheet question types

The lab worksheets, which the author coded against TIMSS Science question types of 2015 (Jones, L. R., Wheeler & Centurino), had 78 questions in total. This was in addition to procedural prompts or advice on using equipment, whose role is not studied in detail, but the talk related to which is included in the analysis in chapter 8.

The purpose of using a coding system for the worksheets is to make sense of the alleged breadth of questions as well as the balance in factual and analytical questions presupposed in the design, as first explained in FIGURE 7 and the design embodiments.

The lab worksheet questions were marked by the author and, choosing from TABLE 12, given the most suiting code for the question. Since it was possible that the author read something more into the intent of the question than what was actually printed, two reliability coders were asked to revisit the coding.

7.2 Intercoder agreement for worksheets

At first, the reliability of the coding scheme was assessed through 15 questions taken at random (representing 22% of the total number of questions in the worksheets). This was done by generating[9] a sequence of 15 random numbers between 1 and 68, the first number of questions coded. The corresponding questions were selected from the list of all question codes in alphabetical order. These questions were coded by two other coders, without training other than to follow the TIMSS

[9] Generated at https://www.random.org/sequences/.

guide (Jones, L. R., Wheeler & Centurino 2013, pp. 55-57). The intercoder reliability was inadequate. It was described by average pairwise Cohen's kappa as 0.41 or Fleiss' kappa as 0.398.

After a one-hour discussion with the reliability coders, they offered two helpful considerations. First, it was difficult to code the questions without seeing them in the context of the whole document (particularly the preceding and following questions, and placement of the question as an introductory one or as one of the concluding questions). Second, the discussion showed also the importance of considering the classification of the question types under "Knowing", "Applying", and "Reasoning", when deciding between two possibly suitable codes. As a third discovery, some questions seemed to have two parts that corresponded to separate categories (e.g. F12 q16: "What kinds of problems did you encounter during your measurement? Underline the problems you expect to apply to measuring with an actual Atomic Force Microscope.").

The two-part questions discovered in the sample were split, and three more such cases were discovered, increasing the number of questions coded by the author to 73. Reviewing the worksheets of 2013, 5 clarifying questions had been added to the 2012 worksheets (3 in Electrophoresis, 0 in Force Microscopy, 1 in Nanoscale Magnetism, and 1 in the Gold Nanoparticle lab). Now the number of questions coded by the author in total was 78.

After this, I revisited all of my coding, paying close attention to the higher-level classification of questions and the exact wording of the coding manual. To make the reliability coders' task more similar to the author's, one of the worksheets was randomly drawn (the Gold nanoparticle lab of 2012) and its 15 questions (representing 19% of the new total) were coded by both.

The agreement of the question type coding was now deemed adequate, with an average pairwise Cohen's kappa as 0.807 and Fleiss' kappa as 0.806. As a note, most problems arose in between the categories of "Draw conclusions", "Synthetize" and "Analyse" – what they have in common is the demand of using various factors in determining the overall cause-effect relations, and in the analysis, it might make sense to also look at these questions in combination.

7.3 Results: Distribution of different question types

The distribution of different question types in the four labs were compared after ensuring the coding as reliable.

The worksheets seemed to have slightly different emphases on certain question types, but overall did not peak in a particular category. The maximum number of the same type of question per worksheet was 5 ("explain" in Gold Nanoparticle and "provide examples" in Force Microscopy) and the minimum 0. The type "justify", which was about making an evidence-based statement about the reliability of results, did not appear among the worksheets even once.

In FIGURE 8, the question type distributions are shown for the whole set of lab worksheets in 2013 (the figures for 2012 differ by five less questions). FIGURE

9 shows the balance of the overarching categories of knowing, applying and reasoning types of questions in the worksheets.

From FIGURE 8, we can tell that no single question type is overrepresented in the set. The types "provide examples", and "describe" (within Knowing), "compare", "explain", "relate", "interpret", and "use model" (within Applying) are at an equal standing at 7-9 instances. There are slightly fewer appearances of "recall" (Knowing), "analyse", or "draw conclusions" (Reasoning) – four or five of each. The remaining Reasoning category questions appear once or twice.

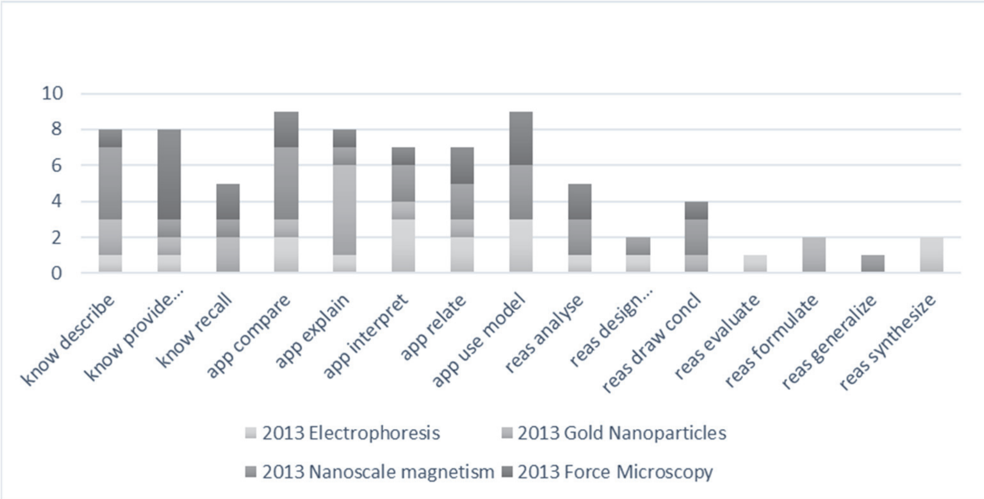


FIGURE 8 Count of different question types in the worksheets of 2013. The precursor "know" denotes the Knowing domain, "app" the Applying and "reas" the Reasoning domains.

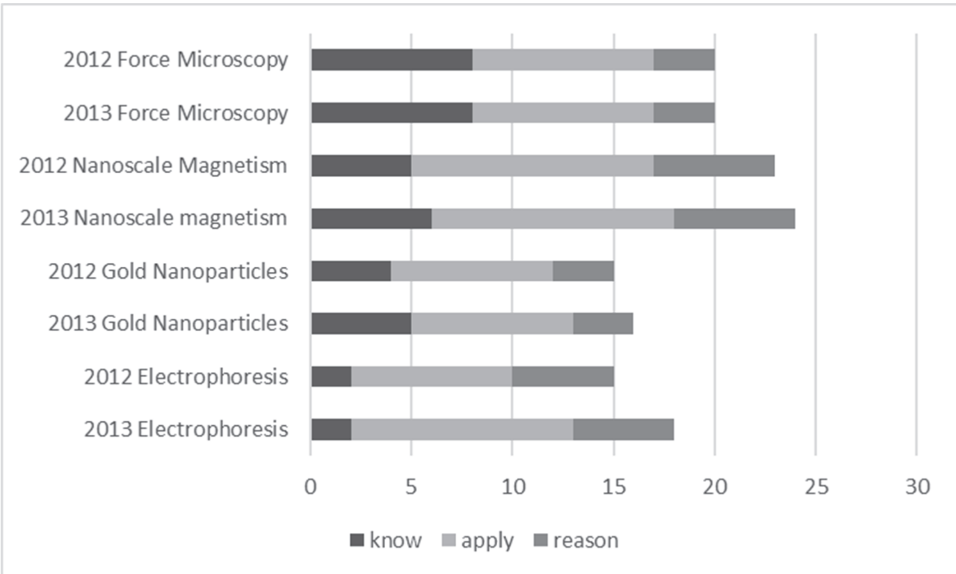


FIGURE 9 Division of question types within worksheet amongst the overarching categories of knowing, applying and reasoning

Looking at FIGURE 9, the category of Applying information is strong across all worksheets. These questions are in the midway of the "factual" questions in the domain of Knowing and the deeper analytical questions in the domain of Reasoning. The overall impression of the question distribution is that the laboratory worksheets have a balance in the factual and the reasoning types of questions.

Looking for differences between the laboratory worksheets, Force microscopy has the highest amount of questions in the category of Knowing, while Electrophoresis has the fewest. On the other hand, Electrophoresis and Nanoscale Magnetism have most questions in the Reasoning domain. It might be interesting to look closer at the question types within each laboratory worksheet (see FIGURE 10, FIGURE 11, FIGURE 12, and FIGURE 13 through the following pages).

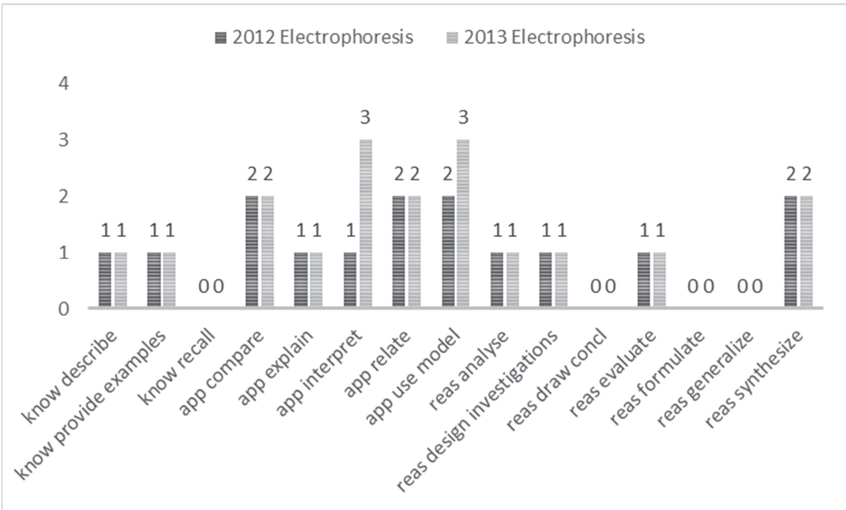


FIGURE 10 Question type distribution in the Electrophoresis laboratory worksheet. The precursor "know" denotes the Knowing domain, "app" the Applying and "reas" the Reasoning domains.

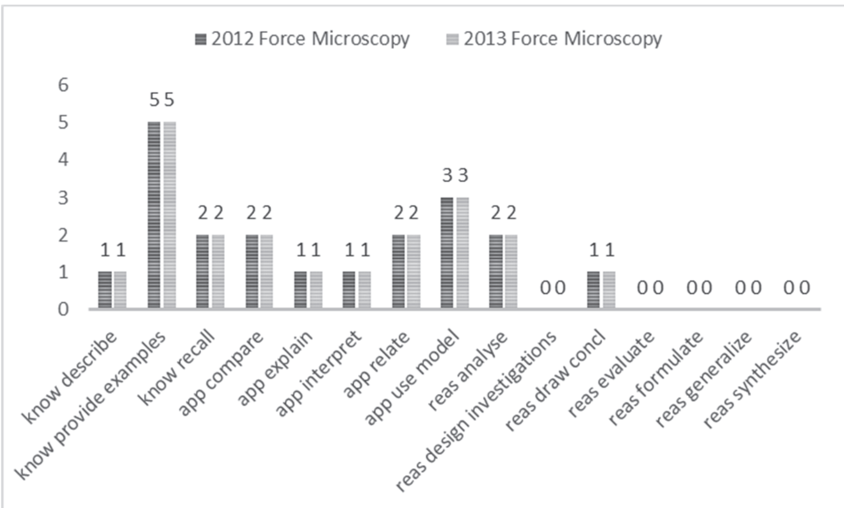


FIGURE 11 Question type distribution in the Force Microscopy laboratory worksheet. The precursor "know" denotes the Knowing domain, "app" the Applying and "reas" the Reasoning domains.

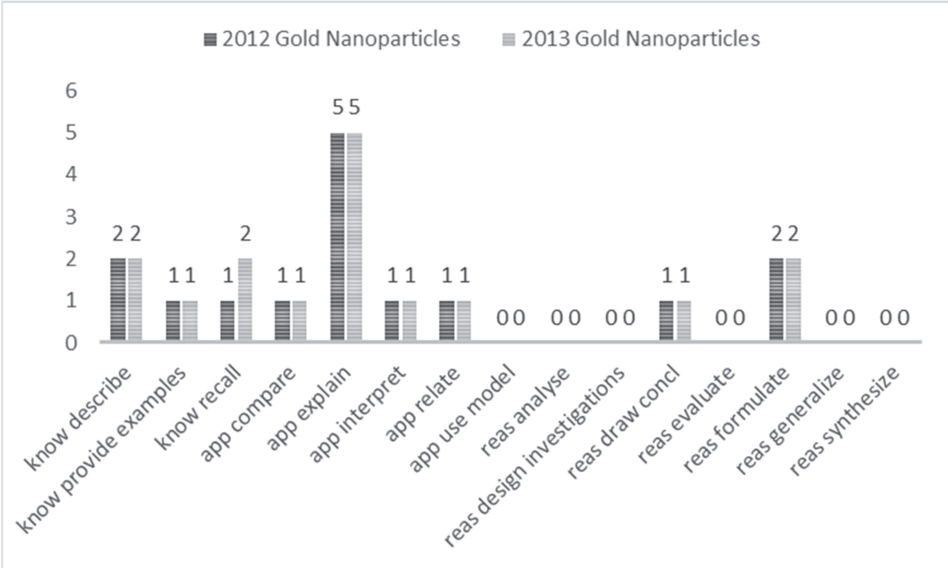


FIGURE 12 Question type distribution in the Gold Nanoparticles laboratory worksheet. The precursor "know" denotes the Knowing domain, "app" the Applying and "reas" the Reasoning domains.

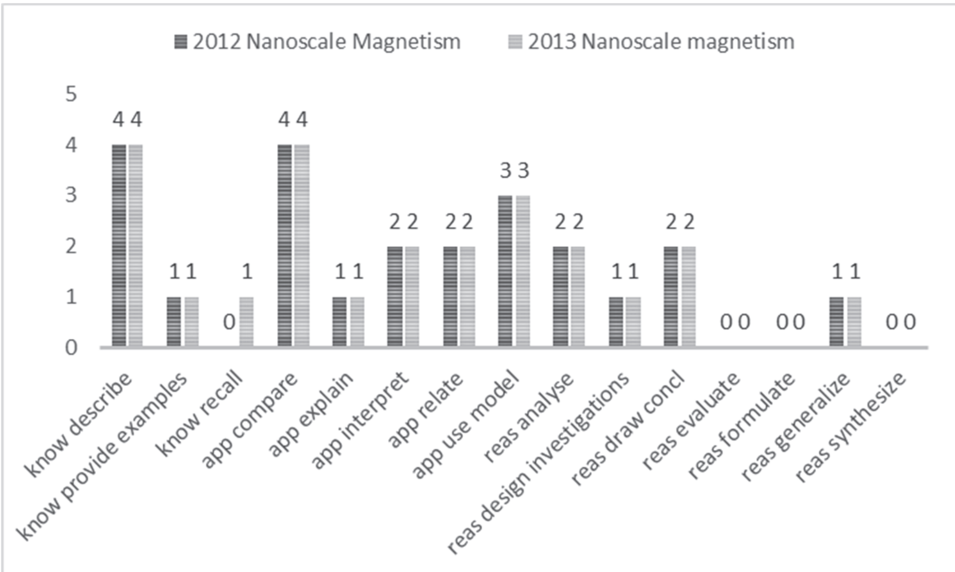


FIGURE 13 Question type distribution in the Nanoscale Magnetism laboratory worksheet. The precursor "know" denotes the Knowing domain, "app" the Applying and "reas" the Reasoning domains.

The particular questions in each lab session are varied, and they should be as the worksheets were never designed using the TIMSS question typology, but rather as best adheres to the topics under consideration and to give possibilities for students to bring up possible differences between disciplines and to participate in all students' expertise areas, whether it be offering simpler facts or engaging in reflective, analytical problem-solving.

7.4 Design of worksheets aligned with design goals

The design of worksheets, as it has been partly in my hands and partly borrowed, was a black box initially: did it really meet the expectations of the whole design construct? Using a measure well tested in other contexts, the TIMSS science question typology, provides a fair overview of how the questions used are distributed across the different domains of problems. It is difficult to give a preferred measure for how balanced the distribution should be. I can point to evidence that the questions in the worksheets definitely are varied, within domain and through all three domains, for all four laboratory sessions.

The next chapter attempts to answer the question of whether the balanced distribution really aids students in attaining the actions the design calls for, the mediating processes – in terms of the question types, most interesting is how the interdisciplinary group talk dimensions of Reasoning and Knowledge appear across the questions. Even though the questions were not linked to group behavior or social skills in the design conjectures, I am still interested in seeing whether certain types of questions offer better opportunity than others for the students to utilize these social skills during the labs - i.e. the Peer dimension.

8 ANALYSING THE STUDENT TALK

8.1 Pairing talk related to worksheet questions

This step of the analysis was made without a coding manual. Content-driven recognition of topics that were relevant to answering a certain question, paired with the knowledge of the order of questions in the worksheet, was used to determine which turns of talk belonged to a certain question.

The talk could also be related to carrying out a procedure outlined in the worksheet, in which case it was coded as "Procedure" talk. Sometimes the students spoke of something else entirely, such as lunch break or weekend plans, and these were coded as "unrelated".

As the teacher of this course, it was deceptively easy to point out which question the group was trying to answer where, and to follow their discourse through the worksheet. The coding felt very obvious. Perhaps several years of working through the material with the students really had helped me internalize the content to the extent I could usually tell which problem the students were tackling from overhearing half a sentence, even in the teaching session. I felt then, and again while coding, very tuned in. This could be a problem if it was not possible for someone else relatively familiar with the content to make the *same* connections between worksheet question and student talk. It was crucial to have a second opinion about the worksheet questions, but it would have to be from someone familiar with the content and the laboratory session.

Thankfully a biosciences graduate student, with whom I co-taught the course since 2016, agreed to code one group's session to establish intercoder reliability.

8.1.1 Intercoder reliability for Talk related to worksheet questions

The reliability of pairing of talk per worksheet questions was split into two parts; firstly, the reliability of locating talk related or unrelated to the questions, and the reliability of assigning these spans of discussion to a particular question in the worksheet.

The session was picked at random by lining the transcribed texts up, generating[10] a sequence of 14 random numbers, and choosing the text corresponding to the first number of the sequence. This was the group M13-g4 (see TABLE 11), working on the Magnetism at Nanoscale lab in 2013.

This discussion corresponded to 1134 turns of talk or occasional interpretations of non-vocal activity, such as "picking up supplies" or "long silence".

The reliability coder was invited to assign the worksheet codes to the spans of discussion she felt were related to them. She did not have a particular coding manual other than the worksheet questions for this task. She was chosen as she shared a similar background as the author – classroom experience from this course - for recognizing the kind of talk related to a certain question.

Overall, coding each turn of talk with the correct worksheet task or 0 for unrelated, the intercoder agreement was adequate (Cohen's kappa 0.79). Looking simply at recognizing question-related talk – is it coded or not - the agreement was slightly poorer (Cohen's kappa 0.75); this means the coders had a slightly different threshold for including talk as question-related. Viewing the codes in detail shows that many of the differences were located in the opening or closing turn of the question-related talk. These instances were typically sounds of agreement ("huh") or bordering between procedural talk and opening for a question ("can we demagnetize it now?"). Nevertheless the transcript had still several pieces of talk that the reliability coder did not assign to any question, while the author did.

Looking at the recognized relevant spans of talk, the coding reliability can be looked at in terms of how many of these discussions acknowledged are coded to the same question. The discussion count works as follows:

One discussion can be a span of turns that is marked with different codes by the coders (attributed to different questions) or a span within non-attributed talk that is recognized only by one coder. If there is a span of agreed upon codes next to a span of coded and non-related talk, the widest attributed span for this code is recognized as one discussion all relating to the same code. The overlapping span may be at the beginning, the end, or the middle of the discussion; or the discussion may have "holes" not attributed to a question by the other coder within.

This division of data yields 69 discussions for comparison and the intercoder agreement is adequate (Cohen's Kappa 0.79). Out of the 12 disagreed upon discussions, three happen with a question concerning hysteresis and its "neighboring" questions (the coders attributed talk either to relating to how substances' properties are shown in the hysteresis curve or to "just" drawing the curve –

[10] Generated at https://www.random.org/sequences/.

which indeed is difficult to tell apart). There are 2 other sequences where the other coder overlooked a student trying to initiate a discussion on the next question, or checks the answer for previous question. This appears as a discrepant discussion, although typically just a turn or two in duration. An example of this is given in the following sequence, where the S1 reads parts of the next question from the paper and the students S2, S3, and S4 continue to discuss the procedure for solving the previous problem:

0966 S1: Ferrofluid behaviour as superparamagnetic. How do the above --

0967 S2: -- I would have probably tried, like, using five for *r* maybe.

0968 S3: Oh? What's the use in doing so?

0969 S2: You get a relation --

0970 S4: You get an area and a volume --

The results indicate that it is possible to get a reliable attribution of the student talk to a question in the worksheet. To use the question typology for these coded questions and cross-tabulate with talk types, each turn of talk matters (as it may contain a specific speech act coded towards a talk type). The Cohen's Kappa 0.79 for agreement per turn is adequate for this purpose.

8.2 Recognizing and coding the dimensions of interdisciplinary group talk

The codes are based on ideas in section 6.4 and ultimately, the learning goals for these laboratory sessions.

The original idea was to code separately for supportive interaction and invitations to participate in the discussion ("Peer") and affective, personal level familiarity ("Affection"). After the initial coding, once another person was invited to code a lab session, it became clear that this distinction was not easy to make. These codes were eventually combined (see sections 4.3 and 6.4.2) into one code that signals positive interaction with group members; this makes sense, since both ways of relating with one's peers are meaningful in collaboration – the ability to support and use peer help in solving problems, but also building relations that go beyond a course. Together they make up a whole dimension of managing peer relations in interdisciplinary group talk.

So in the end, the coding helps us see the three dimensions in doing interdisciplinary group work: the interpersonal skills and collaboration, managing and switching between the knowledge and epistemology of all relevant disciplines, and the ability to reason and explain one's thinking. These three skillsets and examples form laboratory sessions are shown in TABLE 16.

The coding, using this final coding scheme, was well aligned. My impression was that the "Argument" and "Knowledge" codes do sometimes appear at the same time, but there was a distinction between the dimensions and that was also picked up by the reliability coder. The difficult area was perhaps the "Knowledge" dimension, particularly in discussions where the students negotiate the validity of a result or action. The students had a hard time doing this, too.

TABLE 16 The coding scheme for dimensions of interdisciplinary group talk. This final version containing all modifications based on reliability coder discussion. Grey background represents the turns coded. Other turns are for context.

CODE	Example sequence coded into this dimension	Basis for coding
Peer	Enacts skills that are relevant in working with people and building a positive atmosphere.	
	S1: But what do we have for this first [question]? S2: One swings and the other doesn't? S1: How about in the first one charge is evenly distributed and the other one it's not. S2: Yeah that's good.	Asks peers for contribution; encourages peers.
	S1: Ligands are kinda like these – S2: you're the chemistry student. S1: -- attachments that stick on the surface of a complex ion. S3: yeah. S2: so they're attachments that stick on a complex ion. You could publish something on this. S1: hah S2: hah hah S3: so what's a ligand?	Mentions a peer contribution in one's own turn, builds on these ideas explicitly- not just keeping the conversation up.
	S1: Reminds me fondly of the labs in Physics 4 where you had to make them bridges [circuits] and we got like fucking million volts as a result OH YEAH makes sense and we wrote it down. Went to the assistant and sir we jes dunno whatever these are, momentarily there prolly was a minus hundred thousand degrees when me and James were measuring the temperature of the resistance [sic]. S2: No kidding!	Laughter (warm, not mocking). Shares a story/anecdote.

TABLE 16 (continued)

CODE	Example sequence coded into this dimension	Basis for coding
Reasoning	Generic science and reasoning skills	
	S1: I'm thinking they are evenly distributed. S2: yeah! S1: If they are charged and evenly distributed S2: They join, they join through those, the particles have them ions on the surface and the OH minuses come from them. S1: It's in this picture too, I agree.	Elaborates on reasoning, tries to explain reasoning or previous statement in other words.
	S1: So it's ten thousand ex whatever it means [concentration 10 000x]. Eight microliters. How much do we need? S2: Does anyone have- S1: Do you just logically deduce it? S3: Yeah logigally you put one ten thousandth there and its concentration would then be one if that one's ten thousand. S1: Divide by ten thousand? S3: Yeah it's good maths.	Uses a scientific abstraction technique in answering.
	TA: Now when I close this up and we look at the direction of the gels so is this the right way around? S1: Well no, because now the DNA would erupt onto the positive side.	Structures talk as an argument or supplies evidence for a claim.
Knowledge	Skills related to managing different areas of knowledge, points of view, changing stances	
	S1: In the Electricity course all magnetic phenomena were explained with the spin. So in practise like a differential current loop. Inside the body they cancel out, but on the surface, they don't, and it becomes a magnetic field.	Offers factual knowledge, which does not need to be valid. Just tossing concepts is not coded.
	S1: OK do you think there's a field? S2: Yeah it might have. S1: This [compass] arrow's pointing in a different direction from the rest. S2: Mmm. S1: Maybe they're disrupting each other? S2: No but I think it's probably the wrong way around inside, the arrow?	Discusses validity of a result or an offered fact. Involves counterpoints or other reasoning; not just disagreement with a peer

TABLE 16 (continued)

CODE	Example sequence coded into this dimension	Basis for coding
Knowledge	S1: If we put the atom in a magnetic field and take it out would it stay [magnetized]? S2: If it won't, then it ain't. S1: Would you count magnetic dipoles or should it be on the macro scale – S3: -- discernible S2: I mean it has a magnetic field but it's not the atom's fault we don't have the equipment to detect. S3: At least in the traditional understanding.	Negotiates choice of point of view, e.g. disciplinary, or between theory and observation, or scope of the answer.

8.2.1 Intercoder agreement for coding dimensions of interdisciplinary group talk

One of the thesis supervisors agreed to code one group's session to establish intercoder reliability. The session was picked at random by lining the transcribed texts up, generating a sequence of 14 random numbers, and choosing the text corresponding to the first number of the sequence. This was the group F13-g2 (see TABLE 11), working on the Force Microscopy lab in 2013. This discussion corresponded to 1338 turns of talk or occasional interpretations of non-vocal activity, such as "rattling noise".

This session was analysed in a similar manner as the coding for question-related talk. Looking at the recognized relevant spans of turns, the coding reliability can be looked at in terms of how many of these discussions acknowledged are coded to the same dimension code, or several codes. The discussion count works as follows:

One discussion is a span of turns that is marked with one or several dimension codes by at least one of the coders. If one coder has marked several codes, the discussion codes are compared separately for all codes (the discussion is counted as many times as there are codes for the same span).

If there is a span of agreed upon codes next to a span of coded and non-coded talk, the widest attributed span for this code is recognized as one discussion all enacting the same dimension. The overlapping span may be at the beginning, the end, or the middle of the discussion; or the discussion may have "holes" not attributed to a talk code by the other coder within.

This division of data yields 82 discussions, which contained seven instances of discussion marked with two codes. The intercoder agreement is low; Cohen's Kappa is 0.71 for agreement per turn.

The coders met for a discussion around the coding manual, final version of which is used in the thesis, and narrowed the categories for the Peer dimension code and the Knowledge dimension code. In the Peer code, simply responding to peers should not be coded, unless the students explicitly use parts of the previous answers in their speech. In the Knowledge talk code, agreeing or disagreeing with an answer is not talk about validity; talk about validity requires commenting on why they doubt or agree with the result/suggestion.

With these revisions in coding, the data contains the same 82 discussions and gives an adequate Cohen's Kappa at 0.80. This shows that these fairly general attributions of meaningful, learning goal relevant talk types can be reliably coded using the coding scheme shown in section 6.4.2.

The reliability coding showed how easy it was to slip and interpret any discussion about agreement as validity talk, and the author proceeded to revise her coding throughout all coded transcripts.

Some evidence for reliability of this talk coding can be attained from what little evidence was left from the first round of coding which was lost because of file loss. This is considered in Appendix 3. As the code set was not exactly the same during both rounds, one can only make some assumptions about the reliability on that basis. My interpretation is that in using these coded turns and making connections between question types and the interdisciplinary group talk dimensions – as is done in the following – that the large proportions of co-occurrences (the C-coefficients) are a believable indicator of a connection, but the frequencies may vary by several occurrences between these two coding instances, and small differences are impossible to point out through this method.

8.3 Connections between the question types and dimensions of interdisciplinary group talk – evaluating design choices

The Atlas.TI code co-occurrence tool was used to produce a chart that reflects the connections between the dimensions of interdisciplinary group talk and the worksheet topics during which they occur. For comparison purposes, charts with the simple numbers (frequencies) for co-occurrences are prepared as well. This goes to show what kinds of talk co-occur the most frequently – which is good for visualizing what goes on in the lab groups. But to analyse connections between a certain kind of question and its "resultant" talk requires the analyst to relate the number of co-occurrences to the total numbers of occurrences of each talk separately, and that was the purpose of calculating C-coefficients in the code co-occurrence tool. These charts for questions, laboratory procedures, and unrelated talk are provided in the subchapters below.

8.3.1 Discussions on answering worksheet questions

The frequencies of co-occurrences in the transcripts are reported in TABLE 17. Calculating occurrences of each code or dimension is not particularly informative; there is large variance in how long (how many turns of talk) a coded sequence can be. Some question-related talk can span 120 turns: a long discussion which considers different aspects of the problem, such as the “Synthesize” type question in Gold Nanoparticle 2012 Group 1's discussion. Some questions are glanced over very shortly and one student gives a satisfying answer in one turn.

The dimensions of interdisciplinary group talk are usually at sequences of a few turns, because they are examples of interaction within the group, and therefore tend to involve participation of more than just one group member. An obvious exception to this is the Peer dimension, when it is coded on grounds of laughter of any group member.

The co-occurrences therefore do not follow a pattern in terms of a question encompassing a dimension of interdisciplinary group talk, or vice versa.

The Peer dimension in TABLE 17 contains many more ″hits″ overall than the other two dimensions; this follows partly from the peer code being in use more than twice as much as the other two dimensions (Peer: 534 instances, Knowledge: 226, and Reasoning: 174). This makes it invalid to compare frequencies across categories, and such comparisons best be left to comparing the C-coefficients.

TABLE 17 Frequencies for the co-occurrences between dimensions of interdisciplinary group talk and the talk related to types of questions in the worksheets

		Dimensions of interdisciplinary group talk		
Talk related to question types		Reasoning	Knowledge	Peer
Knowing	Describe	5	13	30
	Provide Examples	10	17	33
	Recall / Recognize	16	26	26
Applying	Compare, Contrast, Classify	17	14	22
	Explain	14	25	12
	Interpret Information	18	14	40
	Relate	24	16	24
	Use Models	12	8	21
Reasoning	Analyze	13	13	20
	Design Investigations	2	7	9
	Draw Conclusions	12	7	7
	Evaluate	0	2	4
	Formulate Questions / Hypothesize/ Predict	12	9	10
	Generalize	4	4	3
	Synthesize	5	2	2
	Justify	0	0	0

Perhaps noteworthy from perusing this frequency table is that even the question types which occur only in one of the worksheets (Evaluate and Generalize) are triggering some of the dimensions of interdisciplinary group talk. I will now leave the frequency table alone and discuss the C-coefficients in TABLE 18.

Viewing the data of TABLE 17 against the C-coefficients in TABLE 18 makes for an interesting comparison. Because the c-coefficient is related to the overall number of occurrences in both categories, the highest numbers of co-occurrences do not always show up as high values of c-coefficient. The aim of this analysis was to discover interesting connections in the data rather than to seek direct cause and effect between a specific question type and resulting discussion. I am careful not to make these kinds of claims because of the size of this sample – for some question types, just a few turns of talk in three separate groups – as well as the breadth of the categories that link into each dimension of interdisciplinary group talk. I will come back to this discussion again in section 10.5.

TABLE 18 C-coefficients for the co-occurrences between dimensions of interdisciplinary group talk and the talk related to types of questions in the worksheets. The table is color-coded for visualization of the values for C-coefficient (ranging from 0 to 1).

		Dimensions of interdisciplinary group talk		
Talk related to question types		Reasoning	Knowledge	Peer
Knowing	Describe	0,02	0,05	0,05
	Provide Examples	0,05	0,07	0,06
	Recall / Recognize	0,09	0,11	0,05
Applying	Compare, Contrast, Classify	0,08	0,05	0,04
	Explain	0,07	0,1	0,02
	Interpret Information	0,09	0,05	0,07
	Relate	0,12	0,06	0,04
	Use Models	0,06	0,03	0,04
Reasoning	Analyze	0,07	0,06	0,04
	Design Investigations	0,01	0,03	0,02
	Draw Conclusions	0,06	0,03	0,01
	Evaluate	0	0,01	0,01
	Formulate Questions / Hypothesize/ Predict	0,07	0,04	0,02
	Generalize	0,02	0,02	0,01
	Synthesize	0,03	0,01	0
	Justify	0	0	0

The c-coefficients that have the highest value appear for the co-occurrences between the dimension of Reasoning and the question type Relate (0.12); the dimension of Knowledge and question types Recall / Recognize (0.11) and Explain (0.10). Pairs that follow close behind are nearly all questions in the domain of Applying knowledge and the Reasoning dimension of interdisciplinary group talk, as well as the Interpret Information question type being the top match with Peer dimension.

I will continue to draw examples from these matching categories to understand why they might be showing up in the analysis. Before the examples, one tabulation is in order. The reliability coding discussions in section 8.1.1 included the idea of pairing up the question types of Analyze, Synthesize and Draw Conclusions – all in the domain of reasoning. The reasons were partly because they were difficult to distinguish in coding, and the underlying reason of course was that the categories contain similar elements: they all include comparing information and making connections between ideas to come to a conclusion. The frequencies and C-coefficients for this combination is shown in TABLE 19.

TABLE 19 The frequencies and C-coefficients for co-occurrences between the dimensions of Interdisciplinary Group talk and the suggested combination of Reasoning question type categories Analyze, Synthesize and Draw Conclusions. The table is color-coded for visualization of the values for C-coefficient (ranging from 0 to 1).

	Dimensions of interdisciplinary group talk		
	Reasoning	Knowledge	Peer
Frequency	30	22	29
C-coefficient	0,15	0,09	0,05

Aggregating the question data in TABLE 19 increases the C-coefficient quite a lot; both Analyze and Draw Conclusions already showed quite high c-coefficients separately but paired together they contribute to a high c-coefficient of 0.15 with the Reasoning dimension.

8.3.2 The Recall / Recognize question type

Now starting with the question types in the domain of Knowing; the Recall / Recognize type seems to co-occur with both Reasoning and Knowledge dimensions. The co-occurrences happen in seven different group discussions, meaning the connection is not just the product of one group happening to talk in this way. The question type occurs in three lab worksheets and the co-occurrences also – so it is not likely to be just one good question within this type.

The group 2 in the 2013 Nanoscale Magnetism session is an example of such a discussion, as they answer the Recall question of what is meant by hysteresis.

S1: Ahh! ferromagnetic substances stay magnetic even after
the field is removed. This phenomenon is called

3 hysteresis ((reads from a website)).
4 S2: Yeah.
5 S1: So hysteresis means that the magnetic field stays --
6 S3: -- even if the external field is removed --
7 S1: -- that substance is left with some kind of own field.

The Reasoning dimension is coded over rows 5-7 where students 1 and 3 elaborate on what S1 initially read from the web page. They are explaining it again in their own words. The Knowledge dimension is coded for S1's first turn (rows 1-3) as the student provides factual knowledge.

This is typical of these 16 instances of overlap with the dimension of Reasoning: they co-occur with or near the dimension of Knowledge. The students answer the Recall / Recognize question with a factual statement and then clarify or re-word if they were not previously familiar with it.

Sometimes they don't, and such instances build up the co-occurrences with Knowledge only, such as this sequence from 2012 Force Microscopy group 4, where the group tries to recall the size of an atom:

S1: I'm thinking it's --
S2: I'm not carrying my MAOL [book with data tables]
S1: -- one ångström so 0.1 nanometers.

The group doesn't contest the answer and they move on to the next task. Just a handful of the Knowledge dimension examples are more interesting as they involve the decisions of which point of view to take – for example when the 2013 Force Microscopy group 2 attempt to recall terminology relevant to interactions between two atoms (this is analysed more closely in section 9.6). But most of the discussions in this category are quite simple fact-clarification-sequences.

8.3.3 The Explain question type

The Explain question type in the domain of Applying knowledge has a high c-coefficient with the dimension of Knowledge. The explain questions occur in all four laboratory worksheets, but the coded talk only comes from two laboratory works (Gold Nanoparticles and Nanomagnetism). The question in Force Microscopy has some co-occurrences with the dimension of Reasoning but the question in Electrophoresis has not triggered any of the dimensions. The electrophoresis lab question of this type was to explain why some of the lines were darker than others in the resultant photograph of the gel electrophoresis results; the students either didn't know the answer or guessed, or due to lack of time during this lab, this question was often answered together with the TA or teacher and the whole class at the very end discussions, which were not coded (as they were not small group talk).

The explain question types were ripe with facts, particularly the ones form Gold Nanoparticle labs, as they were on questions asking students to explore ways in which various objects become colored – and the explanations required the students to go through these facts. Example from Nanomagnetism 2012 Group 4:

S1: I'm answering that liquids can't function as magnets. Their constituting parts move past one another and they don't stay organized.

The student is answering the Explain question without really explaining in an explanation format; she is offering a piece of knowledge but not really linking it to why this refutes liquids as magnets. The assumption here is unsaid. Later in the discussion the same group the student formulates the same argument again, elaborating while offering a piece of knowledge:

S1: OK so can a liquid be a magnet? So if we take it that a magnet produces a magnetic field. Right?
S2: Yeah
S3: Yup
S1: And they're mixing so you can't get a stable structure that produces the magnetic field.

These structures are typical of the explain question type; because the reasoning part is so often implicit, the question is getting a lot of overall with Knowledge dimension and not quite as high (C = 0.7) on the Reasoning dimension.

8.3.4 The Interpret information question type

This question was noted to have high co-occurrence rates with both the Reasoning and the Peer dimensions. There are Interpret information questions in each of the laboratory worksheets, and the co-occurrences with Reasoning dimension are found in each of the lab sessions – by ten separate groups of students; same for the Peer dimension (11 groups).

Here's a representative example from 2012 Electrophoresis Group 2, discussing over a diagram of DNA internal structure and tasked on figuring out which part of DNA is affected by the electric field in the electrophoresis method:

S1: Which part does it effect on, the phosphates?
S2: Yes I think so if they have charges
S1: OK in principle the hydrogen bonds also have a charge distribution
S2: Mm
S1: But that, the phosphates are… ah well
(pause)
S3: Phosphates I think that's the answer
S1: Yea it's ok. But still they have the hydrogen bonds which have a charge distribution, so shouldn't those be affected somehow?

The explanation student 1 gives is in the Reasoning dimension; he starts to devise an argument about hydrogen bonds and returns to this argument on the last line. He's also involving his peers in the discussion by asking the others' opinion. This technique is quite successful and both students 2 and 3 take part and use the contributions of S1 in their comments.

It's very typical of the students, in terms of this sample, to explain their understanding of the diagrams or figures (or even scientific articles) in their own words, before they start answering the related question – this was what all Reasoning discussions co-occurring with this question type involved. The interpretation step is very closely linked with the Reasoning dimension and it is not surprising to find this connection. Nearly every time they also confirm their ideas with their peers, asking for their opinions or confirmation.

In frequency, the Peer dimension is co-occurring with this question type a lot more than Reasoning (co-occurrences with Peer: 30, Reasoning: 18). The remaining co-occurrences are quite varied; many involve laughing at some part of the information or the frustrations of not being able to figure it out, as the group 3 in Gold Nanoparticles 2012 experienced:

S1: But *why* would it get *darker*?
S2: Because reaction
S1: Ha ha ha
S3: That's encompassing!

The other acts that end up coded in the Peer dimension include just asking the rest of the team if they have any success with the question.

8.3.5 The Relate question type

The relate question type, too, is found in all laboratory worksheets, and it occurs in connection with the Reasoning dimension with the c-coefficient of 0.12. The discussions are distributed across the lab works, and the co-occurrences are from 10 different group discussions.

Some of the discussions were hardly discussions, but rather short initial attempts at the problem followed by long pauses where the group members kept thinking: for example, in 2012 Gold nanoparticles group 3:

S1: You could say that the gold particles, they group and then around the will be those charged sodium particles... so is it then electric interactions... oh, no, it said between the *nano* particles!

In contrast, some of these co-occurrences span more than 20 turns of talk; for example the 2012 group 4 in Force Microscopy worked very thoroughly on the question of which atom-level interactions are modelled with the foam plastic, giving arguments first in favour of the strong nuclear force and then electric interactions between the electron shells.

In all of these discussions, the shared reason for being coded with the Reasoning domain was that the students were argumenting for why they thought the issue at hand was related to the question, and were trying to convince their peers. The students made well-structured arguments in this question more than in the other question types in the domain of Applying knowledge.

8.3.6 The Analyze, Synthesize and Draw conclusions question types – the domain of Reasoning

The question types within the domain of Reasoning had fewer occurrences in the worksheet per each question type – overall there were about as many Reasoning questions as there were Knowing questions (see section 7.3), but as the Reasoning questions were spread over so many categories, there weren't as many instances per each category.

The Formulate Questions/Hypothesize/Predict question type gives rise to interesting discussions and is well represented over each dimension of interdisciplinary group talk. The problem with making inferences from this finding is that the two instances of this question type are both located in the Gold Nanoparticle lab, even if the three different Gold Nanoparticle lab sessions in the data are all well represented in the co-occurrences! The same problem follows the analysis of other singular question types within the domain of Reasoning.

In TABLE 19 however I devised the combined category of three similar question types in the Reasoning domain, and found that it has a high C-coefficient with the Reasoning dimension – which is very well in line, as evidenced in the naming of the domains and dimensions.

In the combination, we have questions and related discussions from each of the lab sessions ranging over 10 separate groups – a good variety in the groups as well as topics: any findings are not confined to a single topic, which was the problem initially.

In these discussions where the codes co-occur, students are suggesting different explanations for phenomena (Magnetism 2013 Group 2)

S1: If that nano size iron particle is the size of one domain then do you think it would be the same amount [of domains in a large iron filing] like how many nano size particles it could fit inside?
S2: A-ha!
S3: Is it, like, it's capped to that size.

They also seek confirmation on their interpretations (2013 Gold Nanoparticles group 1):

S1: Yeah doesn't this picture make you think like there's the minus ends here, so you get chlorine from sodium chloride, and it grabs a hold there?

And they provide quite intricate explanations for phenomena. Some of the turns are quite long, where the student explains a long process or their understanding of all factors which influence the decision, from start to finish in one turn. For example, Student 2 below describes the factors affecting how DNA travels through a gel (from Electrophoresis 2012 group 2):

S1: OK, in principle, the longer it is the more electric charges it's going to have, and more mass 'swell
S2: But isn't it the relation of charge compared to size and mass, it stays the same,

so in principle the size stays the same since the shape is the same with the ions there that keep it from folding. So it's only the length which is changing.
S3: Mm. But there's also the part of how well it can separate those lengths.
S2: Well the longer ones go slower.
S1: Yeah in principle.

The discussions in this category represent all aspects in the Reasoning dimension of interdisciplinary group talk. But looking back at the discussions, most of them contain the Knowledge dimension as well – the students often are discussing the validity of the interpretation. This is reflected in the high C-coefficient on co-occurrence with Knowledge dimension (0.09).

8.3.7 Talk during laboratory procedures

To find out if the procedures in the laboratory settings were a substantially different setting from answering a specific question in the worksheet, the discussions concentrating on a procedure or setting one up were coded and the Atlas.TI code co-occurrence tool was used to have a quick look at the differences between these activities.

A total of 144 discussions connected to executing a laboratory procedure were recognized. The procedure talk varied from very short snippets between answering questions in the worksheet to prolonged periods containing pauses and occasional comments on the equipment they were looking for or observations on what they were creating.

TABLE 20 The frequencies and C-coefficients of the co-occurrences in talk during procedures and the dimensions of interdisciplinary group talk

	Dimensions of interdisciplinary group talk		
	Reasoning	Knowledge	Peer
Frequency	8	29	130
C-coefficient	0,03	0,09	0,24

The main feature of these discussions is that most of them contained talk in the Peer category (see TABLE 20). It inclueds laughing together or prompts for other group members to take on a task, and of these, there were a 130 overlapping instances. This isn't entirely surprising as the procedural tasks allow for freer expression – to be coded as talk around a certain question, it's about this certain question, and the students have a goal of answering the question. But if they're puzzled about the equipment or organizing a task, they explore and talk about it with less restrictions. The procedural talk is also more concentrated on the present time and task, which is ripe ground for mistakes or small failures – often resulting in laughter (Lamminpää & Vesterinen 2018).

An example of such is from 2012 Electrophoresis G1 talk, where student 1 (S1) and student 2 (S2) make a gel, which they heat in the microwave oven and mix every now and then, until it is completely dissolved. They are observing if it has become see-through, without visible strings or wisps of agar-agar:

S1: Has it heated up yet?
S2: Well it's clearer than before but it's not quite there yet.
S1: It's done!
S2: It ain't clear all the way.
S1: Oh, now it went back to cloudy.
(all laughing)
S1: Yah. Thanks to my mixing skills.

The group goes on to discuss coursework while they continue heating and mixing, and eventually is satisfied with their product.

The Knowledge talk type is the next most prevalent in this category; the students are figuring out which perspective to take or need factual information to proceed with the task. They often negotiate whether their experiment is "done" and this falls into the Knowledge talk type, such as in this excerpt from Gold Nanoparticle lab 2012 Group 1:

S1: I think it's boiling
S2: It isn't bubbling
(pause)
S3: We'd know it's done if we saw some bubbles
(pause)
T: Once you've added both ingredients, you need to be mixing continuously
S3: How strict is it that it's actually boiling?
T: Well you wait 'till you see that it's bubbling. It needs to be… it looks like it is almost there
(pause)
S3: OK. I declare now this to be boiling. Does anyone want to come and mix when I start adding?

The three students are looking for the right moment to add the next ingredient. The second and third student seem to equate boiling with the sight of bubbles, and perhaps the first (S1) is looking at other visual cues such as vapour or condensed steam on the neck of the Erlenmeyer flask. They make sure with the teacher and wait until it is certain ("I declare now") that the liquid boils. They are making choices on the validity of signals and their interpretation as "boiling".

8.4 Disciplines and interdisciplinarity occurring in student talk

This section gives an overview of discussions students have where disciplines are brought up explicitly. Some themes that arise are explored here, as well as the types of interaction or worksheet question types that co-occur with the discipline mentions. This overview can be read as an introduction into the analysis in chapter 9. Whereas the goal in that chapter is to analyse particular instances of group discussions, here I will examine the breadth of different topics or circumstances that brings about the mention of disciplines amongst students themselves.

In the entire transcribed data, there are 97 instances of talk *explicitly* bringing up disciplines, coded under the Disciplines code. A major feature is its overlap with the Peer dimension (18 instances). Of these, roughly half are laughter and half inferences that the other student should answer this question, as they're an expert (Snippet from Gold Nanoparticles 2012, group 1):

S1: So was it that you're studying chemistry?
S2: Yeah?
S1: You could walk me through this since I'm no good at it.

TABLE 21 Frequencies and C-coefficients of discipline mentions co-occurring during the other categories of talk (Question types, Lab Procedures, Unrelated talk, and the Dimensions of interdisciplinary group work)

Categories of talk			Frequency	C-coefficient
Question types	Knowing	Describe	3	0,02
		Provide Examples	3	0,02
		Recall / Recognize	8	0,07
	Applying	Compare, Contrast, Classify	1	0,01
		Explain	6	0,04
		Interpret Information	6	0,04
		Relate	2	0,01
		Use Models	4	0,03
	Reasoning	Analyze	1	0,01
		Design Investigations	1	0,01
		Draw Conclusions	1	0,01
		Evaluate	0	0
		Formulate Questions / Hypothesize/ Predict	4	0,04
		Generalize	0	0
		Synthesize	2	0,02
		Justify	0	0
Experiment procedures			9	0,04
Unrelated talk			4	0,03
Dimensions of interdisciplinary group talk		Reasoning	5	0,01
		Knowledge	9	0,03
		Peer	18	0,02

The students sometimes explore stereotypes, veiled into jokes so as to not point at the majors of this discipline in the group (unless they themselves tell the joke). Example from Electrophoresis 2012, G1:

S1: So it's [DNA strand in electric field] probably going from the negative side to the positive.
S2: Yeah that must be it.
S1: You know the physicist approach, like, let's see what happens.
S2: Yeah that's what it is!
(both laughing)

Out of the question types, the Recall question type (under the category of Knowing) is best represented with eight co-occurrences, and the highest c-coefficient for any discipline talk overlaps, 0.07. Some co-occurrences are instances where the students are trying to attribute their knowledge to a source – they heard it on a course in the specific disciplines. The disciplines are short-hands for course titles, such as in these turns on answering what a colloid is:

> "No no, I'm not talking about ligands, it's -- I mean it was maybe in Chemistry 1 or Chemistry 2" (2012 Gold Nanoparticles G1)
>
> "Oh! I think this was in Chemistry 2 --" (2013 Gold Nanoparticles G1)

Sometimes disciplines were used during Recall question is as if locating the disciplinary setting for this question – or at least for the answer. The students are referring to these locations where their answers are placed in these turns:

> "It [atomic size scale] had those Ångstroms they taught us in biology" (2012 Force Microscopy G4)
>
> "Unless this is from physics, like weak and strong interaction in the nucleus" (2013 Force Microscopy G2)

The disciplines *do* appear during lab procedures, with nine co-occurrences. It means that nearly a tenth of the discipline mentions happen during lab procedure talk. Within the large mass of talk in the procedures, they are not a prominent part of the lab talk however, giving this co-occurrence the C-coefficient of 0.04 only. It is difficult to say if this is in line with the expectations of work with equipment bringing up discussions about the disciplines and intrinsic views of how they work (Fiore 2008). What number of co-occurrences would meet the expectation? Furthermore, the co-occurrences are from just four groups, meaning that poring over the equipment was productive grounds for some groups to consider some disciplinary indicators or differences, but for most, it did not prompt any discussions around these themes. Working with equipment does not automatically equate discipline talk, and the result here sets a baseline for what could be expected for similar settings and group compositions.

The examples of procedures with mentions of disciplines are still interesting; they co-occur with some laughter and often include placing the student in a disciplinary representative role (example from 2012 Electrophoresis G1):

S1: This is the part where it explodes onto everyone's face.

S2: (laughing) I *did* manage to cook something in the Chemistry labs so that it --

There were also several (16) mentions of disciplines or interdisciplinarity mentioned by the teacher or TA. These are not analysed more closely as they don't represent the students' understanding or use of the term. The teacher or TA mention disciplines in the introduction of the lab or to highlight a convention in a discipline:

> "This lab should contain a good deal of physics and biology" (Electrophoresis 2012 Group 1)
>
> "That's the notation biologists use" (Electrophoresis 2012 Group 1)
>
> "If you take physics courses, they'll just tell you this one formula for Van der Waals forces" (Force Microscopy 2012 Group 4)

Sometimes they make connections between the use of certain terminology and a discipline

> "These ones [words] are, like, physics and you're missing chemistry and biology." (Force Microscopy 2012 Group 5)

The occurrence of such talk is evidence on myself and the TAs following the course design where these disciplinary origins of methods or concepts are discussed explicitly, showing students the occasions where disciplinary borders may be spotted.

9 DISCIPINES AND INTERDISCIPLINARITY – CHANGING STUDENT CONVERSATIONS

This analysis relies on the more detailed transcriptions of conversations as outlined in section 6.5.3. The purpose of this chapter is to show what the introduction of disciplinarity does for the conversations and their participants. All of the conversations that were coded for explicit mentions of disciplines were revisited. The ones that only had the teacher or TA mention discipines were not chosen for detailed analysis. They are referred to in section 8.4.

The conversations chosen below represent different ways of using the disciplinary references in conversation, and an attempt for variety from different years and lab work sessions. The selection process was to pick out and analyse the conversations until the mentions of disciplines seemed similar in function to the already analysed pieces, resulting in comprehensive treatment of the available data.

9.1 EF2012 Group 1. "Precise enough for a physicist"

The first task for the group is to make their electrophoresis gel. Before this part, they have just identified all the equipment on their desk, and are now ready to go weigh ingredients. There's a queue to the scale, and the TA suggests they start with a calculation of the dye content to use for the gel.

The discussion involves the teacher's assistant (TA) and three students S1 (chemistry major), S2, and S3 (physics majors).

1	TA:	siinä samalla kun sinne puntariin on jonoa ni voitte
		so while you're queuing for the scale you can
2		laskee sen ee tee bee är (.) liuoksen tarvittavan määrän
		calculate your e t b r (.) solution the amount ya need
3		sinne (0.4) ↑kohassa neljä
		there (0.4) ↑in part four
4	S2:	mm. (0.5) mites tää nyt sitten menee taas (11.0)

mm. (0.5= how'dya do this stuff again (11.0)
5 S3: .hhh
.hhh
6 ((rattling noise)) (49)
7 S2: >*.hh hh hh hh hh*< *((fast, sharp laughter))*
8 S1: niinpä
yeah I know
9 S3: ↓onks nää oike::sti mikrogrammoja.
↓are these re::ally in micrograms.
10 S2: on?
yes?
11 S1: on
yes
12 S3: sit tätä on (.) aika pirun vähän (0.7)
then there's (.) damn little of this stuff (0.7)
13 S2: .h joo.
.h yeah.
14 ((clothes rustling))
15 S2: totta (2.0) mutta mutta (7.0)
true (2.0) well well (7.0)
16 S1: saatteks te sen laskettua vai=
are you getting it done or=
17 S3: =noei=
=*nope*=
18 S2: =tsheheh hehheh heh hhh (1.5) nnnh (0.5) antakaa (.)
=*tsheheh hehheh heh hhh (1.5) nnnh (0.5) just gimme (.)*
19 hitausmomentti tai jotain sen mää kyl saan laskettua=
a moment of inertia or sumthin I shur can manage that one=
20 S1: =ehehheh heh emmää tiiä se mittaa vaan et me tiietään
=*ehehheh heh I dunno it's just to make sure we know*
21 periaatteessa (.) yks tilavuus vaan siitä=
in principle (.) just one volume of it=
22 S2: =mmm (2.5) noniin (10.0)
=*mmm (2.5) okay (10.0)*
23 ((chair squeaks, TA directs another group, microwave clangs))
24 S1: no nyt me voijaan mennä (.) ↑varmaan hhh
ok I think we're good ta go (.) ↑ I think hhh
25 S2: nojoo (12.0)
okay (12.0)
26 S1: kuin paljon tota tota piti olla
how much of that did we need
27 S3: nolla pilkku kaheksan grammaa.
zero point eight grams.
28 S2: .hhh joo.
.hhh yeh.
29 S1: haluutteks ↑te punnata (.) vai punnaanko mä.
do ↑you wanna weigh it (.) or do I.
30 S2: siekin voit.
why don'you.
31 S1: ah (.) aika semmost [jotenkin tosi
ah (.) it's like [somehow really
32 S2: [mmm

		[*mmm*
33	S1:	puista. (11.0)
		woody. (11.0)
34	S3:	mmm. (13.5) valkosta jauhetta (3.0) ootteko ihan varmoja
		mmm. (13.5) white powder (3.0) you guys sure
35		ettei se oo kokaiinia?
		it ain't cocaine?
36	S1:	[hh
		[hh
37	S2:	[hmyh hmyh hmyh hmyh (1.2) en ehkä lähtis kokeilemaan.
		[hmyh hmyh hmyh hmyh (1.2) I might not wanna try it out.
38	S1:	mm (.) takuuseen
		mm (.) warranted
39	S3:	hh sitä vois vähän ottaa vähän tot taskuun ja myyä kadulla (0.9)
		hh you could take a sample with ya and sell it off the streets (0.)
40		oottaa (0.3) nistiä pieni yllätys. (2.5)
		a tiny surprise (0.3) awaits the junkie. (2.5)
41	S1:	°( ) ostit multa°
		°( ) buy from me in the first place°
42	S2:	hmh?
		hmh?
43	S1:	siis et mitäs ostit multa thh
		like why'd you buy from me in the first place thh
44	S2:	nhii:: (7.0)
		ah yea:: (7.0)
45	S2:	ei se kovin kaukana enää oo
		it's not that far any longer
46	S1:	kelpuutatteko tämän punnitustuloksen (4.5) onko
		you ok with this weighin result (4.5) is it
		tarpeeks tarkka?
		precise enough?
47	S2:	no ei me sitä sieltä enää poiskaan hh enää taieta saada.
		well we sure ain't getting it out hh of there any longer.
48	S1:	hhe=
		hhe=
49	S3:	=fyysikolle tarpeeks tarkka!
		=precise enough for a physicist!
50	S2:	nhöhhöhhöh (.) [niimut (.) onko] noita
		nhohhohhoh (.) [yea but (.) is] there
51	S3:	[mäki tarkotin et]
		[I just meant that]
52	S2:	mut onko tossa soluille tarpeeks tarkka ni se on toinen kysymys.
		but is it precise enough for the cells well that's another question.
53	S3:	hnii, (2.5)
		ah yes, (2.5)
54	S1:	pystytteks te jompikumpi ottaa mulle noi ylös ni pystytään
		could either of you guys write those down for me so we can
55		tarkistamaan (1.2)
		check it up (1.2)
56	S3:	↓mmjoo (.) pieni hetki (8.5)
		↓mm yea (.) just a sec (8.5)
57	S2:	elikkä meillon=

so we got=
58 S1: =nolla piste kaheksan
= zero point eight

The students did not know each other from beforehand and are not very comfortable, signalled by the long pauses and short chuckles. They are slow to get started working together.

The physics students S2 and S3 are categorizing themselves as physicists in this chosen sequence. None of the students are biology majors, and they are all openly expressing difficulty with the calculation of the dye content. The group members all chuckle when the difficulties are mentioned, but the whole group never breaks into shared, hearty laughter. The physics students avoid giving direct answers to questions they are uncertain about. In this piece, both use the physicist categorization to accomplish this. When asked if they could calculate the dye content, one quickly admits "no". Student S2, after some laughter, laments by saying he could calculate the moment of inertia for an object. He doesn't answer the initial question, and finds a way to respond that portrays him as successful in physics (if not in biology).

Student S3 invites the others into joking about drugs and elicits positive responses from both S1 and S2, as they laugh and join the fantasy episode. S1 offers her contribution to the joke but the other two don't seem to hear, and S2 elicits a repair. S1 repeats her words but isn't successful in getting her group to laugh.

The group tries to return to the task at hand with S1 asking her group members about the precision of their measured amount of agar. S2 and S3 continue with a joking tone, and S3 invokes the stereotypical physicist that makes wild, sometimes inappropriate approximations. They do not actually give an answer to that or the precision question themselves – they only refer to the Stereotype Physicist to answer to the other student, and their talk overlaps as S3 attempts to continue his turn after S2's genuine laughter. S2 continues to talk and continues the joke onto biological subject matter ("precise enough for cells"). S1 doesn't join the joking this time and persists with another task-related request. The group returns to work quietly on their gel making.

The discussion shows one way of the students use disciplinary identities. They are comparing themselves against the stereotype to portray themselves in positive light and to contrast with another discipline that is not present. They're also setting the example of making one's own disciplinary stereotype the butt of a joke.

The same joking on one's own disciplinary stereotype occurred in several occasions; for example, the 2013 Nanomagnetism session group 4 which used the stereotyping joke several times through their session. A recurring use of disciplinary identities was to use them as insertions into pre-existing jokes or sayings. Sometimes they're very laconic mentions, sometimes one student is simply telling the others a joke he or she had heard about mathematicians or chemists, and sometimes the jokes come on the spur of the moment as the group is bent over laughing over a blunder. All of these occasions abide by the same rule as shown above.

The use of the stereotype disciplinary representative categorization compares interestingly with the example Day and Kjaerbeck use in understanding the positioning in a group one native amongst non-native English speakers in an English language task (Day & Kjaerbeck 2013, p. 26-27): "[a participant's] status as a native speaker of English differed from the linguistic competence of the rest of the group at all times, but this fact can be used in different ways in the group's discussion. As the discussion became more confrontational, [the participant] contributed to this development by making his identity as a native English speaker, and therefore a linguistically more competent person, relevant in the talk."

In this course's context, the identity of self was *also* made relevant in the talk when it was downplaying one's situational expertise or skillset: the physicist who couldn't answer anything but physics questions, or a physicist who couldn't stop fiddling with equipment until it broke (in 2012-NM-g4). In fact, there were no examples of a person asserting their own competence in a subject through this self-categorization.

9.2 EF2012 Group 1. "Poor biologist"

The same group with chemistry student S1 and physics students S2 and S3 are halfway through the Electrophoresis lab. They are about to connect the power to their Gel chamber and use the electric field to move the strands of DNA through the gel they prepared. The TA oversees use of high voltage equipment.

1	S1:	virrat päälle power on
2	TA:	siihen virrat päälle turn the power on
3	S1:	hjoo. yeah.
4	S2:	se voi muut [tu- it could be ch [ang-
5	TA:	[s'tulee tonne (.) [jus' put it thar (.)
6	S2:	niin tulee. yeah puttin'.
7	S3:	onks toi ristikko tossa ihan vaan sen takia ettei onneton biologi are the crossbars there just so that a poor biologist
8		vaan (.) ty- (.) pienesti työnnä sinne käsiään? wouldn't (.) pu- (.) tend to put his hands in?
9	S2:	<älä multa kysy.> (1.5) <don't ask me.> (1.5)
10	S3:	tai (.) ↓estääkö se jonkun ↑ulostulon? or (.) ↓is it stopping something from getting ↑out?
11	S1:	nh nh
12	S2:	voi ol, (.) voi ↑ol could be, (.) could ↑be

13	TA:	okei elikkä nyt siinä on virta päällä ja [nyt tota (.) alrighty so now you've got the power on and [now ya (.)
14	S2:	[vissiin toi pääl [guess put it on
15	TA:	laitatte päälle sen koneen. ↑pommista= ya can put the machine on. ↑from the bomb=
16	T:	=täältä= =in here=
17	TA:	=joo =yes

The students' banter shows them much more comfortable as a group – they have got their lab going and are talking more lively and at a faster pace.

S3 makes a joke through categorizing here, too, but is now making the joke about a discipline other than his own. He pauses and makes a self-initiated repair during the joke, inserting the word "tend to" to soften the joke (rows 7-8). This turn does not get any laughter from the group. S2 rejects the joke explicitly by responding "don't ask me" with a pronouncedly unexcited, slow pace. After a pause, S3 tries again and places biological subject matter as the target of the joke, receiving accepting utterances and responses from both group members (rows 11-12). The group negotiated here whom they would make jokes about, and seemed to draw the line at making fun about other disciplines not present in the group.

Curiously, the TA and the teacher are standing right next to the group, commenting (on rows 2-5 and again 13-17) on all student actions except the biologist joke!

As this was the first lab session (not just for this year, but for the course entirely), the groups and teachers were still groping around to see how this course is run. What's the teachers' role, what about the TA, are they students or staff? What kind of jokes do the teachers or the other students reinforce?

Reminded by this situation, I could recall several moments from the course where I identified more with students than with university staff, and this probably was the TA's (a third-year student) feeling as well. The biology joke was interesting from the point of view of this thesis, but also an example of a situation that would've needed teacher intervention.

9.3 FM2012 Group 4: "Yer from physics, too, or are ya?"

This group has just listened to the overall introduction to this lab, given by the teacher. They turn towards the group and start by introducing themselves, as the worksheet requires them to write down names of all group members. The students John and Jane are majoring in physics, and Danny in chemistry.

1	Jane:	äämm muut jäsenet (.) Dan:ny? ja Jo:hn ahemm other members (.) so Dan:ny= and Jo:hn

2 John: jjoo
yeah
3 Jane: okei (5.0)
okay (5.0)
4 Danny: ja sä olit Jane, eikös=
and you were Jane, right=
5 Jane: [=joo
[=yea
6 Danny: [joo (.) ↓oujea.
[yea (.) ↓oh yeah.
7 ((teacher discusses a lab visit with another group))
8 Danny: hmmm
hmmm
9 ((mechanical pencil clicking))
10 John: ni (.) tssä oot (0.3) f::ysiikalt kans (.) vai ooksä
so (.) yer from (0.3) ph::ysics too (.) or are ya
11 Danny: mäoon kemialt.
m from chemistry
12 John: aija (1.5) hh (.) tehkää ryhmässä lista
oh ok (1.5) hh (.) make a list in the group
13 ↓asioista ((lukee paperista)) (2.5) hmm
↓on things ((reading aloud)) (2.5) hmm

Jane remembers all her group members by name already, and they get a quick start on this naming task. Danny remembers Jane from the previous labs or the lectures, but it seems like John and Danny have not met before. John ventures a guess that Danny is from physics, like himself, and makes sure by asking ("yer from physics too" on row 10). He makes tiny pauses through his turn, offering places for Danny to take a turn and confirm. As John finishes his guess and the expected confirmation does not come, he makes a repair "or are ya". Danny has stayed silent until then and now responds with a quick "m from chemistry". John acknowledges this with an equally quick "oh ok".

They are a little puzzled for a second after this mischaracterization, and John takes a short pause before closing the introductions and starting on the task by reading it aloud.

While you surely can't be expected to tell someone's disciplinary identity by their looks, getting a personal detail wrong feels odd and the person getting it wrong may feel ashamed. This group's short exchange shows that even for first-year students it was upsetting to mistake someone for a student of a different discipline.

In 2013, towards the end of the course during the Nanoscale Magnetism lab, the group 4 had a similar incident where they mistook a physicist for a chemist (one of them calculated they had two physicists in the group, and the third corrected her saying it was three). This happened nearly at the end of the lab, and as mentioned, the end of the course – any initial discomforts had already been diminished considerably – and the group ended up laughing about this misidentification together. The reactions are rather dependent on the circumstances, and this sensitivity is maybe connected to the crucial, initial impressions.

9.4 GN2012 Group 1: “You might somehow enlighten me”

This group is now getting started with the experiment, having finished an information-seeking task about colors in general. They are orienting with the experimental task, equipment and guidance questions. The students S1, S2 and S3 are not mentioned by name, but the fourth student here is referred to by name (Cole).

1 S1: nii joo, tuo (1.4) sä oot, vissiin luet kemiaa?
so um this, you're, like you're studyin chemistry?
2 S2: joo
yeah
3 S1: voisit valaista jotenkin minua kun mä en osaa näitä.
you might somehow enlighten me since I don't know this
4 S2: mun pitäis ehkä käsittää tää ((naurua))
I should prolly have an understanding of this ((laughing))
5 S3: ((lukee paperista)) työssä käytettävät kemikaalit
((reads from sheet)) chemicals in this experiment
6 ovat ärsyttäviä (2.5) Tunnenkin kuinka verenpaineeni nousee.
are irritating (2.5) I can suddenly feel my blood pressure rising.
7 S2: ((naurahtaa)) (tauko) <No kun mä veikkaan että siis (1.9)
hehh <Well then so I guess that uh (1.9)
8 tuolla toi (1.7) kloori varmaan ↑pelkistyy (1.9) jollon koska (1.4)>
there's the (1.7) chloride probably is ↑reduced (1.9) so then (1.4)>
9 me halutaan saada noita kultahiukkasia niin sillonhan
we want to make those gold particles so then
10 sen kloorin täytyis tuolt ympäriltä pelkistyä ni sit
the chloride ought to reduce from around thar so then
11 nää lähtis ◦tuolta tavallaan niinkun irti◦ (1.6)
these would take ◦off from there like so◦ (1.6)
12: Cole just (2.2)
right (2.2)
13 S2: mut mikä täällä hapettuu? (4.3)
but what is oxidizing here? (4.3)
14 S1: mä en muista niitä (3.7)
I cannot recall those (3.7)
15 S3: mh? (1.7)
mh? (1.7)
16 S1: Hapetuspelkist- ↑he::i .hh £tuolla on tuoreessa muistis=
redox- ↑he::y .hh £he should ave it fresh in memry=
17 [se just] kävi kemia kolomosen tentisä£ ◦siellä oli
[he jus] took the exams in chemistry three £ ◦twas the
18 S2: [.hh aijaa↑]
[.hh ohh↑]
19 Cole: [ahaa↑:]
[ahah↑:]
20 S3: [aa↓]
[ohh↓]
21 S1: hapetuspelkistys reaktiot◦
redox reactions◦
22 S2: £sulla on tuoreessa muistissa siinä tapauksessa .hh

£you do have it fresh in memory in that case .hh
23 paljon tuoreemmassa kun mun£
much moreso than me£
24 Cole: mm. (1.0)
mm. (1.0)
25 S3: kemia kolmonen vai. (0.8)
chemistry three you say. (0.8)

26 S2: nii (0.5) epäorgaaninen kemia= [>siellähän oli hapetus
yeah (0.5) inorganic chemistry= [>they had redox
27 S3: [niin (.) siellä
[oh (.) there
28 S2: ja pelkistysreaktioita vaikka millä mitalla<
reactions there like tons of them<
29 S3: to:tta↑ (.) joo (.) ◦varmaan.◦
o:h sure↑ (.) yehh (.) ◦I suppose. ◦
30 S2: mut eiks tuolla toi kloori vois <ehkä> niinku pelkistyä? (4.1)
but couldnt that chloride there <maybe> like reduce? (4.1)
31 eiku hetkinen se hapett: (0.9) sen täytyy hapettua
no wait it oxid (0.9) it has to oxidize
32 >että se lähtee tuolta<
>so that it gets away from there<
33 S3: Cole pelasta nyt meidät [tästä pois.]
Cole why don you rescue us [from here.]
34 S2: [nii]
[yea]
35 [ollaa] ihan hukassa. ((nauraen))
[we're] just lost here.
36 Cole: [joo↑]
[okay↑]
37 periaatteessa se hapettuu kun siihen (0.8) niin (0.6) siinä on (0.5)
in principle it oxidices when there (0.8) like (0.6) you have a (0.5)
38 periaatteessa siellä se (1.1) se vaatii yhen elektronin ◦siihen◦ (0.8)
in principle the (1.1) it needs one electron to ◦go there◦ (0.8)
39: S2: nii.
yeah.

In this excerpt students 2 and 3 are both identified as studying chemistry, but they take it very differently. S2 admits to S1:s query of identification readily. S1 makes a very tentative and indirect request at S2 (row 3). S2 does not go with the request as she doesn't give the preferred response of agreeing to help S1 out. She doesn't give an explanation of why she couldn't help S1, either, which would be typical of such a declination. Instead she laughs and re-words the meaning of the category she was placed in: she should be able to understand the chemistry content of the question. Laughter here signals her discomfort in the situation – being categorized as someone who knows chemistry, but suddenly having to use this knowledge while she's not prepared to.

After another student's short exchange (rows 5-6) S2 starts to help S1 out anyway, returning to the preferred response for S1's call for help. Her answer is full of long pauses and tentative parts, where her tone of voice raises (e.g. row 8:

"there's the (1.7) chloride probably is ↑ reduced") and at the end of the answer, her voice tapers off, being really quiet (row 11). The other group members accept her attempt at responding the question, with Cole voicing this shortly ("right").

But once S1 realizes that, once the cue word of "redox" is mentioned, that S3 has recently taken a relevant course, he launches excitedly at categorizing S3 as the person who should answer the question. Cole and S2 are equally excited, and they all exclaim on top of one another (rows 17-19).

While S2 took the position of chemist on willingly, S3 is resisting the positioning. He gives an unexcited "ohh↓" (row 20) at the same time as the rest of the group are talking, and then remains quiet while the others revel in the moment, their smiles and suppressed laughter audible – e.g. as S2 directs her words to S3, "£ you do have it fresh in memory in that case .hh £" (row 22) joining in the positioning of S3 as the chemist of the group.

S3 asks for confirmation (row 24) and takes his time acknowledging the confirmed information (row 29), giving his answers with pauses, slowly and in a low voice. His resistance to this categorization is productive, as S2 picks up her position as the person in charge of the redox reaction explanation, and offers the group a possible solution for assessment. S3 is "off the hook" and he joins the conversation now in a more firm tone, positioning Cole as someone who has the answer. S2 adjusts to this situation and voices her alignment with S3's categorization with a pointed "yea" (row 34).

Similar demands and positioning groupmates for expertise were expressed several times for example in MG2013 group 2, GN2012 group 4, but not in all of the labs. Some of the students on the course had started their minor studies in other subjects (or had a strong background from high school), and they sometimes had about the same amount of studies in a discipline than did a major student. Turns out that there wasn't as much demand for specific expertise in all groups. The categorization was useful when the speaker did not have specific knowledge in the subject area, but could deduce that it belonged to the discipline represented by another student. The speakers sometimes presented the categorization very rigidly (such as another student asking, "What's the opinion of the physicist?" positioning the physics student into the narrow role of The Physicist of the group).

The categorization of peers into their discipline started to take hold as an accepted way of showing they recognize some behavior that adheres to a discipline as the course progressed. Such behaviour for example was the connection to learning about sniffing samples in the lab. This excerpt is from MG2013 Group 4, where the students were trying to find differences between iron filings in oil and the ferrofluid by sniffing them:

1 S1: °thää thuoksuu jännältä° ((imitoiden päihtynyttä)) (1.5)
°thhis shmellsh funnee° ((imitates being wasted)) (1.5)
2 S2: [<↓duu:::d>]
[<↓*du::::de*>]
3 S3: [hymh] (1.5) meille opetettiin eilen labrassa
[*hymh*] (*1.5) we were taught yesterday in the lab*

4		et haistelut pitää tehä näin tälleen (0.8) £ mahollisimman *that you need to do your sniffing from like this (0.8) £ as*
5		kaukaa £ (0.5) ei silleen niink= *far away as possible £ (0.5) not like so=*
6	S4:	=aini sää oot kemisth [hi hih *=ah right you're the chemisth [hh hih*
7	(S2):	[hah hhh hh *[hah hhh hh*
8	S3:	£siitä voi kuulema tulla >pahoja ↑seurauksiahh< hh£ *£ I hear you could get all kinds of >bad ↑consequenhh< hh hh£*
9	S2	nii siinä >on se (.) se voi olla (.) se< väkevä ammoniakki juttu *yes that's >ther is (.) it can be (.) that< strong ammonia thing*
10	S3:	joo she hhhhehh hohoh *yeah thh hat hhhehh hohoh*
11	S2:	tuoksuuko tämä sinustakin £ kloroformilta? £ *does this smell like £ cloroform to you too? £*

The students are very immersed in the joke, and they all are laughing genuinely. Only S3 is inserting some more serious ideas into the conversation (rows 4-5). The categorization in this case is not so much related to others wanting to utilize S3's expertise, but rather to point out that her talk about the lab rules made the others view her as a "chemist". She is not positioned as the butt of the joke even though the joke is clearly based on doing the opposite of what her advice was; S3 joins in on the laughter on rows 8 and 10 as genuinely as the rest. But she changes her tone from serious to laughing, and already on row 8 frames herself as someone who's heard the chemists' warning messages rather than being the chemistry person giving the message ("I hear you could get …").

While it ends in a different manner from the first example, the incident directly follows the working rule of calling the person out when one recognizes a discipline-related behaviour or quality. A different version of this was the students' use of discipline recognition out of the categorization of people, as exemplified in the next section.

9.5 GN2012 Group 3: "This really is absolutely chemistry"

This group is returning together after a short information search task in the beginning of the Gold Nanoparticles lab. Student 1 (S1) comes to check on student 2 (S2) while S2 keeps browsing online. Jason is a third student in the group and the fourth student is not mentioned by name. They reflect on the lab to follow, as they wait for the rest of their group to finish the task.

1	S1:	tota (2.5) ootekste valmiita. *so umm (2.5) are you done.*
2	S2:	no siis mä oon ollu kyllä (.) Jason ne teki kahestaan= *well yea I've been too (.) Jason they paired up=*
3	S1:	=nii joo *=ahh yeah*

4	S2:	luetaas vaikka tätä (.3) nanohiukkassynteesiä!
		so why don' we get to reading bout this (.3) nanoparticle synthesis!
5	S1:	mihinkä asti te oikein kerkesitte? (0.7)
		so just how far did you make it? (0.7)
6	S2:	ainii:: sä et tehny niitä ekoja!
		ohh yea::hh you didn't do the first tasks!
7	S1:	a::h, [okei nii
		a::h, [okay yeah
8	S2:	[ni säet oo tehny niitäh (2.3) hei (.) missäköhän ne (.)
		[so you haven't done em (2.3) hey (.) where'dya think they (.)
9		päästään tekeen kemiaa:: ((singing)) (9.5)
		we're gonna be doin chemistry:: ((singing)) (9.5)
10		((mouse clicking sounds, paper rustling, turning pages))
11		.hhh mä voisin käyä vaikka siel (0.4) virologian((ulosheng))
		.hh i could check up on the (0.4) virology((exhales))
12		sivuilla tu tu tu tsssh
		pages tu tu tu tsssh
13		(7.5) ((mouse clicking sounds))
14	S1:	hei. kultahiukkasii
		oy. gold nanoparticles
15	S2:	↑mm! eikso kiva. (2.5) tää on tosiaan ihan kemian
		↑mm! ain't it neat. (2.5) this really is absolutely chemistry
16	S1:	mm. (0.7) nii no niihän meillä oikeestaan nää on, kyllä (0.4)
		mm. (0.7) well yeah we do actually these are, sure (0.4)
17		selvästi voi jaotella et mikä (0.5) näin
		clear to classify which is (0.5) like which
18	S2:	>totta< (1.5) mut tähän asti on ollu aika (.) niinku
		>true< (1.5) but so far it's been quite (.) like
19		fysiikkaa ja bilsaa mummielestä.
		physics and bio in my opinion.
20	S1:	↑mm.
		↑mm.
21		(7.5) ((clicking, pages rustling))

S2 comes across as enthusiastic and a fast-paced talker. She makes initiatives during the conversation to direct their talk and actions; she suggests they take up reading, announces she's going to check the Virology course pages online, while S1 tends to respond quite shortly. S2 tries to bring up the topic of her being happy to be doing chemistry. As the teacher, I mentioned at the start of the lab that we would be making something more chemistry-oriented than before. There's a long pause as S1 is reading the lab instructions and not responding to S2's prompt. She finally goes "oy. gold nanoparticles" on row 14 and S2 responds in a lively voice, commenting how neat it is. She isn't satisfied with S1's answer and continues talking about the lab being recognizable as chemistry.

Student 1 now picks up the topic and confirms S2's idea (rows 16-17). She pauses before talking more about being able to classify the labs per discipline, starting with some unorganized talk and words for uncertainty ("well yeah" and "actually") but ending with conviction that it's clear which (lab) is which. She continues after a little pause, as S2 doesn't immediately voice recognition of the idea. This time S2 picks up with a quick "true" and continues doing classification.

She ends with "in my opinion" to invite confirmation from the other student and S1 responds with a positive "mm". This conversation ends with a long pause, and they talk a little about the website on screen until the groupmates arrive.

Both students are looking for support from the other in doing this classification activity of the lab sessions. Student 2 seemed to find it important to be able to tell which subject the lab as a whole is, as she kept bringing it up until sufficiently recognized. Student 1 was initially reluctant to comment but she, too, voiced that she found the labs easy to classify. Both students admitted each other's claim to having this skill of classifying labs.

While the labs *were* designed to contain references across the subject areas, the students were quick to recognize some salient features of work in a specific discipline and they had similar discussions to this one throughout the lab sessions, trying to put a label on the whole lab (this group had several occasions, as well as the FM2012 group 5 and GN13 group 1). Initially I felt this was a shortcoming of the course – the students not appreciating the intended interdisciplinary nature of the labs! – but on the other hand, they are trying their hand at recognizing the disciplinary background of a methodology, and this is a valuable skill to have as well.

9.6 FM2013 Group 2: "Unless these are from physics?"

This group is going through a "recall" type question that asks them to recall what is meant by strong and weak interactions. Student 1 has just given a detailed list of chemical bonds and forces that he categorized into strong and weak interactions, when Student 2 questions the viewpoint:

1	S1	(11.0) pitäskö sitä [selittää vielä *(11.0) should we [explain it more*
2	S2	[°elleisitten nää° [°*unless these*°
3		.hhh (5.0) ellei nämä tuu sitte fysiikan puolelta. eli jos nämä *.hhh (5.0) unless these are from physics. so if these*
4		on heikko vuorovaikutus ja vahva vuorovaikutus niinku (.) *are the weak interaction and strong interaction like (.)*
5		ytimessä. (3.5) heikko vuorovaikutus (.) ja sitte *in the nucleus. (3.5) weak interaction (.) and then*
7		vahva vuorovaikutus (4.0) *strong interaction (4.0)*
8	S1	MMM! hh *MMM! hh*
9	S2	tässei sanota [ku tässä] *it doesn't say [cause here]*
10	S1	[£ ala ny sooloilemaan siinä £ hh] [*£ don't you start going solo here £ hh*]
11	S2	siinon se kuitenki se paulin kieltosääntö *here it mentions the pauli exclusion principle*

12	S1	mm (.) kieltosääntö et niinku et (.) molekyylit tekee *mm (.) principle so like so (.) molecules they make*
13		yhdisteitä ja spinit menee aina yhteen suuntaan (.) niin *compounds and the spins always go into one direction (.) as*
14		kauan ku pystyy (1.5) joo (.) hyvä et ollaan kaikki samaa *long as they can (1.5) yeah (.) good that we are all of the same*
15		mieltä tässä kohtaa jo (2.5) .hh vahvat vuorovaikutukset *opinion at this point already (2.5) .hh strong interactions*
16		mitäs me nyt siihen pistetään *what are we going to put there*
17	S2	pistetään nyt ne [ionisidokset] ja kovalenttiset sidokset ja nämä. *let's put them [ionic bonds] and covalent bonds and such.*
18	S1	[mm. *[mm.*

The students are talking about concepts as if having a spatial location in a discipline – a fairly typical geopolitical or territory-based metaphor in discussing disciplines or interdisciplinarity (Augsburg 2006, p. 35). They are expressing an important feature on how they view the terminology: as if located in territories of disciplines.

Student 2 comes up with the idea that the concepts might not be what they initially worked on, and expresses it immediately as S1 is still talking. After S1 finishes, he hesitates a little before starting his turn again from start. S2 is pausing many times as he goes, waiting for S1's reaction. In the end, he just repeats the concepts again until finally S1 responds with a loud "MMM!". S1 has been silent for a long time, processing the information, and his acknowledgment of the new idea does not sound happy.

S2 starts to give account on why he is suggesting something different from S1's previous explanation. S1 interrupts S2's account with a joking "don't you start going solo here", reprimanding S2 of bringing a competing point of view to the table! S1's blame worked in that at the end, S2 offers that they choose to use S1's original explanation without even mentioning the "physics" explanation again.

This example was not very well in line with the hoped outcomes of the course, even though it had a good example of one student noticing a disciplinary border and comparing two explanations with the vocabulary question. Regardless of the final choice the students made, this is an example of the students using the disciplines as expressions for places or locations, situating their answer as having come from these locations into the neutral ground of this lab.

The expressions of disciplines as locations or territories is combined with the literal use of disciplines as shorthands for locations, i.e. the buildings which house the departments of Physics, Chemistry or Biology (for example the groups FM2012-g4, EF2012-g2). It's not just the students; during the afternoon groupwork on Force Microscopy in 2012, the PhD student who has organized these students a tour to the AFM measurement station, comes in to visit the lab and exclaims, "I've never been here at Bio[logy] before".

A similar way of framing a concept in a discipline happens during the Nanoscale Magnetism 2013 group 2:s discussion, with different results. There the students try to figure out what is meant by "hysteresis". The chemistry student offers an explanation two times, going unnoticed, and finally puts weight on his words by saying "so in chemistry the hysteresis phenomenon means that it depends on temperature, like, external forces". Locating the answer in a discipline was seen as a useful way for the student to get more attention to his answer. But the rest of the group ignores this turn, too – and continues into the next question.

The other group members can either validate or fault this framing of a concept in a discipline – by exercising their categorization skills, as described in section 9.5.

9.7 Deviant case: a single-discipline group of students

The deviant case of a group with three physics students (F12-g5) was included in the analysis to learn whether the interaction in this group was different from the rest.

Overall, this group with only physics students was not very talkative. They employed short sentences and long pauses between what they did. These features were not unique to the single-discipline group; there were several interdisciplinary groups that talked sparsely. But this at least refutes the possibility that in a group of students who knew each others' disciplinary habits it would somehow be easier to get a conversation flowing.

One of the students in the group used concepts that he identified with chemistry:

1	S1:	(25.0) khm (3.5) noniin laitoin noi mitä oli kemiassa (.) *(25.0) khm (3.5) okay so I put these which were in chemistry (.)*
2		van der waalsi (.) ja dipoli dipoli ja vetysidos (0.7) *van der waals (.) and dipole dipole and hydrogen bond (0.7)*
3		°ja ( ) vetysidos° °*and ( ) hydrogen bond*°
4	S2:	>joo< (.) totta= >*yeah*< *(.) true*=
5	S3:	=>ihan hyvä< =>*that's okay*<

The other students didn't respond to S1:s initial report of the interactions that were utilized in chemistry at first. After a small pause he continued his turn and repeated the last part (some of it was inaudible). Only then did the other students did voice their acceptance of these interactions. The students spoke faster than usually and S3 following right after S2's turn. It suggests they were putting off their responses at first since they clearly were listening (no writing sounds in the background). They were reluctant to evaluate the answers that came with an indication that it was outside their area of expertise. And also, the evaluations that they gave were very short and conclusive, not inviting further talk about these concepts (rows 4-5).

They group launched into a real conversation after this sequence, once S1 asked if they should include Coulomb force and charged particles, which topic apparently was more familiar to students 2 and 3.

Towards the end of the lab, the students talked about lab tours after the lab sessions, and mentioned that the tour for today was something “connected to physics” – they could not remember it during the lab, but they were headed to tour the Atomic Force Microscope, which they interpret as connected to physics. They were exercising their skill at categorizing methods – or laboratories, in this case – much as the interdisciplinary groups were.

The physics student group did not contrast the previous findings, perhaps in part because they had students who had started their minor studies in other disciplines. There were cases during later iterations of the course, where students audibly complained about the lack of disciplinary experts in their group. They thought they were lacking someone from the discipline they identified the lab work with, for example a group of chemistry students working on the magnetism lab (such cases were not available in the data for 2012 or 2013). The physics student group had some mentions of the disciplines in their talk, so it was not just the group composition that brought these discussions about.

9.8 The rules students apply to using disciplines in conversations

Students do make use of the disciplines in their group conversations, and they use them for categorization to accomplish several things. The claims about existing rules within this sample are made on basis of comparing all similar instances of calling out a discipline; the claims were not tested against a previously untouched piece of transcripts mainly because the mentions of disciplines are so far and few; to find out no similar occasions were found would not dispute the validity of the claims made on the data studied in this thesis.

The students position others as members of a particular discipline in two situations; they’re using their recognition abilities on a quality or an action of the student and vocalizing this finding, or they are looking for someone with the necessary expertise they don’t possess themselves. The first category may involve positioning one of the group members as a deviant case (as happened in section 9.4). The chemistry student was singled out as doing something peculiar, and the positioning made her change her tone and course of action in the conversation.

The swapping between different disciplinary perspectives was not easy for the student groups: there was considerable uneasiness both within the physicist group (9.7) upon taking in information labelled as “chemistry” and the group whose “chemistry” explanation was challenged by a “physics” one (9.6). Some of these situations played out with the group evaluating the fit of each answer to the situation and acceptance of both flavours, while others suppressed the other discipline’s information.

The student groups did not engage in joking about disciplines that were not present in the conversations apart from a few instances where someone tried to poke fun at them. The rest of the group did not join in. Other than that, the disciplines were often mentioned in jokes.

Using the disciplines in conversations happened mostly within the Gold Nanoparticle and Magnetism labs. This could be because they were later sessions and the students were becoming more relaxed and this mutual trust had started to form. They were more comfortable in the labs. They certainly were laughing and telling more jokes. The force microscopy lab, too, was sometimes filled with frustrated laughter, which does not have the same function – it is more about saving face and suppressing frustrations about failures (compare with similar findings in Lamminpää & Vesterinen 2018).

10 CONCLUSIONS AND INTERPRETATIONS

Within this chapter I will return to the original research questions:

- Q1. What kinds of skills do students in nanoscience need?
- Q2. How can a laboratory course support the practice of these skills? and
- Q3. What kinds of features of the laboratory session allow the students practice these skills?

In the design process of this laboratory course I have analysed the local, curricular settings for the course as well as surveyed people doing nanoscience in the context. This information combined with a literature-informed overview of interdisciplinary – particularly nanoscience – learning was helpful in defining constraints and goals for the course.

In answering Q1 and Q2, the context and problem analyses in chapters 2 and 3 were the source of information. The ideas were summarized in the conjecture map of the course design: it reflects both the decisions of what the necessary skills are (intended outcomes) as well as how the laboratory course can support the practise of these skills (the designed embodiments). The conjecture map is reprinted here for the reader's aide.

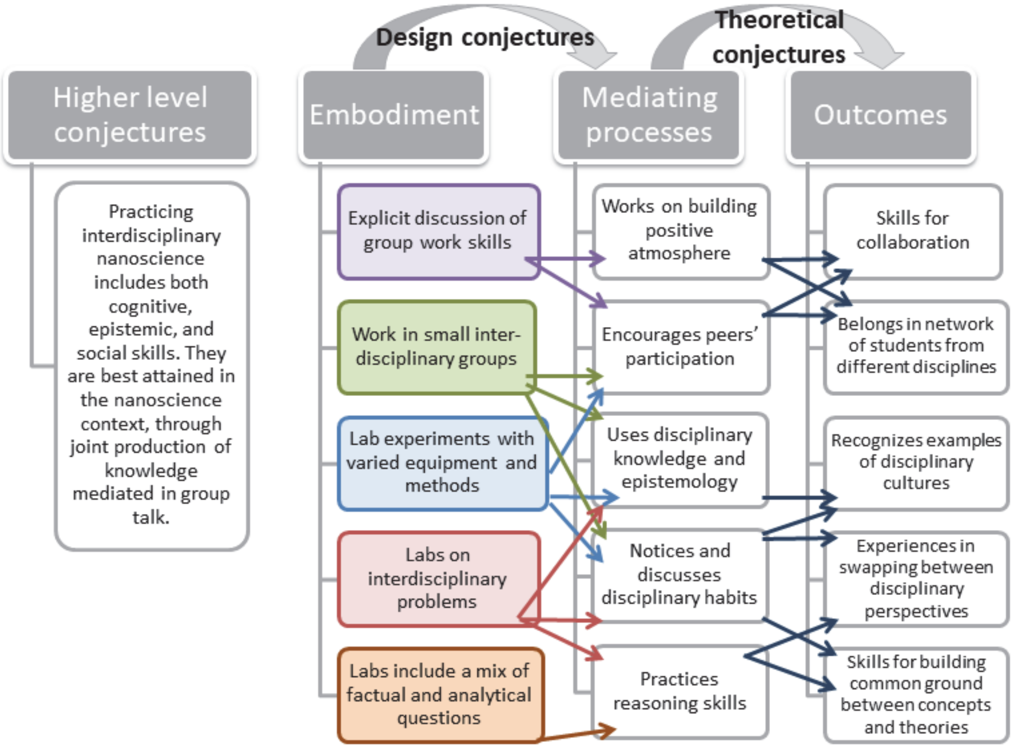


FIGURE 14 The conjecture map of the course design, reprinted from FIGURE 7

Question 3 – what are the features of the laboratory session that allow the students to practise these skills? – is the widest question and the one that the data of this thesis was crucial in answering. The answers are fished out from analysis in chapters 8 and 9; I will go over these mediating processes related to the outcomes in FIGURE 14 in the sections below.

Having chosen Design-Based research as a shape and design of this study, I will come back to the fulfilments of the design cycle. I will also reflect on the validity and reliability of the different parts of this study as well as the ethical treatment of the subjects of this study.

At the end of this chapter I will inform the reader of developments in this course that have happened since the data collection but before the analysis phase of this thesis, and discuss the importance and implications of the findings reported herein.

10.1 Skills for collaboration and belonging in a network

The collaborative skills were in the beginning highlighted by both researchers, students as well as interdisciplinary education literature as of topmost importance. One of the student panel members put it aptly:

"But what skills afterwards, if you're joining the research group, you need something more certainly than that you can work in the lab. You have to have the social skills like for functioning in the group. […] You need some amount of communication skills, and and… well

I'd say they're surprisingly important when, even though you're good at doing things, it isn't necessarily enough."

It's not easy to find the words to describe the constituent skills, but the ability to do interdisciplinary science is heavily linked to one's ability and willingness to work with others.

This study found that actions relevant to making the group work experience smoother and more pleasant – such as encouraging your peers to participate, seeking their expertise, laughing and sharing stories – did happen during the laboratory sessions, and there were by large more instances of this dimension of the interdisciplinary group talk than any others.

A productive site for practising teamwork skills was in all of the Knowing domain questions and their related discussion, but the strongest link was found between the procedural work and the Peer dimension of interdisciplinary group talk. The operating of equipment as well as considering who should do which part of the task – "Who wants to pipette?" – was a rich ground for this kind of discussion. The group work rule setting session in the lessons before lab work weeks worked as the lab sessions were ripe with talk about sharing, taking turns, ensuring that everyone gets to try out a procedure, as well as lots of good-natured laughter.

The explicit goals of a laboratory task in higher education often overlook this dimension – perhaps because the content knowledge is often valued beyond the skills of experimentation and scientific collaboration – but the evidence here suggests that it should be valued as an outcome, as it is a very readily attainable goal for university or high school laboratory work.

10.2 Recognizing examples of disciplinary cultures

The analysis in Chapter 9 concentrated on the student conversations linked with this course outcome. The events where students could point out linkages to disciplines were quite evenly spaced through the analysed group sessions; there were mentions of disciplines in 13 out of the analyzed 14 sessions.

The students practiced their skill of recognizing both people as well as subjects or methodologies as pertaining to a discipline. The close analysis of student conversations showed that not only did they exercise their skill of recognition but that they treated this skill as valuable and looked for confirmation from one another that they had made the right assessment, that the others would recognize the assigned discipline as correct for the topic.

The discussions were interesting to look at as the designer of the course – what I felt was the discipline in question was not necessarily what the students categorized the event as. This is to be expected as there are several examples from the boundaries of disciplines that both disciplines might claim ownership to; for example, the topic of states of matter is viewed as chemistry by chemists and physics by physicists. Awareness of the topics not having a clear-cut division saves me from trying to categorize the student classifications as "right" or "wrong". Therefore I'm leaning towards the view of seeing any classifications as a practice of the skill of recognizing examples of disciplinary cultures, and taking it as evidence of this outcome of the course being met by most groups.

The deeper analysis of disciplinary cultures was not something the students discussed at length. They usually offered their categorization without any elaboration of the statement. In some sense, no matter how detached they were from the course content, the jokes the students told about the physicist, the chemist and the mathematician (or the likes) may have offered most on the front of analyzing the disciplinary *cultures*.

But viewing the course outcome more widely, as recognition of habits and actions relevant to a discipline, as well as having a grasp for its specific vocabulary and concepts, and some of its epistemic concerns such as the value it places on precision of measurements or repeatability, these outcomes were met in the conversations of students in the labs, but not all of these constituents in all of the groups – rather some aspect popping up in each group.

To increase the impact of the laboratory course on this front, I suspect the design of the laboratory worksheets not offering clear points for the students to ponder on the disciplines and their differences. The implicit insertion points of this theme could be made explicit by inclusion of a special symbol denoting a topic where it might be useful to compare disciplinary traditions, vocabularies or some other part of the disciplinary cultures in solving the task.

It might be worth mentioning that about a tenth of these events took place during procedural tasks. The students sharing and talking the lab know-how nicely complements what the nano researchers and teachers said was important in landing a slot in a research group; understanding and having the skills of working with equipment. This expertise was something the students were keen on sharing and the others – not having yet started on lab courses in their minor subjects – equally happy to receive. Even if the discussions were not about very deep epistemological questions, but rather the kinds of pipettes they use at the Chemistry labs but not in Biology labs, they are an example to the other students on what to expect and where (and why) the differences may be. The lab surroundings or the procedural parts did not produce an ongoing banter on epistemologies or habits of thought, and it would be foolish to expect any group interested in the discipline contents rather than philosophy – which it is safe to say this group of students was - to spend a large amount of time dwelling on these.

The fact that these mentions and insights *do* spring up during labs, unprompted by the instructors, but many times prompted by the questions or the use of an equipment, are evidence towards these contexts contributing to students' noticing of different habits, equipment, and methodologies around them.

10.3 Skills for building common ground and swapping perspectives

This outcome arose from the widely shared understanding among researchers of interdisciplinarity that this is a difficult area – building common ground and bridges between concepts or theories that are, in some aspect, incompatible. Upholding simultaneously two explanations that are in conflict is something that the scientist in a single discipline is trained not to do; but to resolve the conflict in an interdisciplinary study the researcher has to be able to get past this idea of a single view and a single explanation holding at a time. The researchers panel mentioned this briefly; one of them reflected on how difficult it was to operate without a "shared ground":

> "A few years back we were supposed to have this collaboration, with [professor from another university], we were modeling [large organic] particles which had like ten to the power of x atoms, and we had to, like, do electron structure calculations – ((everyone laughs)) -- and we did something rather in the ballpark. It didn't work out since the shared ground was so far out. But it was the first tiny attempt to collaborate."

Studying the students' conversation in the laboratory crystallizes just how difficult it may be to operate without the shared ground. As a learning goal for this course, it was not met by many of the students – at least not explicitly. Where the disciplines and their culture or epistemology became the topic of discussion – such as in pointing out the laboratory habits in chemistry or the debate on which disciplinary information would best befit "strong and weak interactions" – the students did not delve into the topic, but rather displayed some discomfort at the possibility of multiple interpretations.

On later years of this course, when the teacher has overheard the group of students on this spot, just a simple notion of the phenomenon they're experiencing ("You've discovered that in physics you are used to using this terminology, while the chemists mean something different by them") has helped them start discussing the difference and working out which choice might be more fruitful for the context of the question.

A simple improvement to test would be to include – in a similar way as suggested in 10.2 – a symbol by the excercises we now know to trigger these discussions; mainly the Force Microscopy lab, where the strong and weak interactions appear in the question. It would be interesting to see whether this visual reminder would work to overcome the discomfort of not knowing which disciplinary view to take (let alone several), or if the teacher or TA intervention here works better.

Since these outcomes were seen as effected also by the questions and question types, a look at the dimensions of interdisciplinary group talk is in order here. The relevant dimensions are those where students negotiate which disciplinary view to take (Knowledge), or how elaborating on how a reaction proceeds and which forces are at play (Reasoning). The task types that are most productive for these dimensions of talk are the Recall questions, the Explain questions and a mixture of the Reasoning domain questions. These questions indeed have the students elaborating their explanations as well as using evidence to support their arguments, as well as negotiating between different points of view or the validity of an observation.

The problem at this approach is that upon looking at the mass of coded discussions, these actions look the "same" to the coding as does offering a relevant fact (Knowledge) or giving a short, argument-structured answer (Reasoning). This choice of lumping different skills together to enhance codability makes it difficult to discern any superstar question types. The best bet may be taking any question in the Reasoning domain; overall, they do produce most reasoning discussions amongst the students, and the only reason why it is so difficult to point at one successful question is because there are so few examples of each kind – one or two – and the groups, in discussing the tasks, vary greatly in how much time or talk dimension they apply to each task. The data, even though there is a plenty of it as a whole, is not enough within the smaller set relevant to this question. I have no evidence-based way of telling whether the students now are equipped for swapping disciplinary perspectives or if they've only had a lot of practise on recounting facts.

I'm relying on The Design Based Research Collective (2003) as they describe design research; as they see it, "methods that document processes of enactment provide critical evidence to establish warrants for claims about why outcomes occurred -- all possible factors cannot logistically be equally pursued; precise replication of an intervention is largely impossible; and emergent phenomena regularly lead to new lines of inquiry informed by current theories or models of the phenomena". The documentation of the mediating processes goes already a long way as evidence, even though the prevision level in my documentation is not as detailed as I would in retrospect have liked.

10.4 Reflection on the course design process

10.4.1 The Design-Based Research cycle

The course design and its testing on years 2012 and 2013 have been documented in detail as far as the laboratory sequences are concerned. The focus of Design-Based Research, as expressed by Barab and Squire (2004), is to "characterize the situation in all its complexity, much of which is not […] a priori". This study has upheld to this through its use of both course design elements as well as the conversations – the site of the mediating processes – on the course meetings. The findings, as they are characterized, look at "multiple aspects of the design and develop a profile that characterizes the design in practise" (ibid).

I realize that this thesis falls short on its execution of only one cycle of the design research; after evaluating the course – much of which focused on evaluating the expressions of the mediating processes, and very little actual evidence of attaining the outcomes! - the proposed changes have yet to be made, while the course has continued its existence. It is possible to realize these changes in the next time the course is taught and collect data, but it will be outside of this thesis. However, the acquired understanding of the various question types as well as the role and use of discipline-recognition in students' talk are relevant and interesting findings that resulted already from this one round.

But in summary, the design objects fared well in terms of attaining the outcomes of collaboration and networking skills, recognizing examples of disciplinary cultures, and practising skills of building common ground between concepts and theories. Some noticing and discussing disciplinary habits did happen on the course, while the evidence on actual perspective-swapping between disciplines is thin. It is either the literature-based belief that this mediating process leads to experiences of swapping perspectives that is wrong, or the mediating processes were not fulfilled as much on all relevant parts of the Knowing and Reasoning dimensions; we already raised suspicions that some areas of these were more meaningful to these learning goals, but that it wasn't possible to track them down using this coding.

The design is not necessarily flawed, but the chosen way of looking at it here falls short for making definitive statements. A different way of coding the materials, as well as trials of introducing markers some exercises as suggested in sections 10.2 and 10.3, would be my suggestion for getting more data and more relevant data to base decisions about this outcome on.

10.5 Quality, reliability and validity

10.5.1 Quality

The quality of the designed course can be evaluated on the basis of its relevance, construct validity, practicality and its effectiveness (Plomp & Nieveen 2007, p.29). The relevance of the course is high; the need for the intervention was well documented, and the goals set for the intervention were not met by any other possible interventions already in place (i.e. the other courses in the programme). The design was based on scientific knowledge as befit the needs originally stated.

The consistency means that the intervention was designed so that it had internal logic; there was reason for choosing any of the parts of the intervention. The use of the conjecture map in FIGURE 14 ensures the consistency of the design.

There is little data to evaluate the practicality or usability of the intervention; the teacher of the course also being the designer means that for the teacher, the intervention was indeed usable in the settings. The views of students on this matter, i.e. the clarity of instructions, the schedule, the possibility to attend etc. are not widely known, although some individual instances of wording-related issues were evident from the learning diaries of the students – and fixed as found.

The effectiveness of the intervention relates to how well the outcomes were attained. The shortcomings were outlined in the previous section; on an overall scale, the intervention can be called effective.

10.5.2 Reliability

The Design-Based Research Collective (2003) suggest that the reliability of design research be promoted through triangulation from multiple data sources, as well as repeated analysis through the cycles of design and implementation. Seeing that the present study only offers one cycle of design, the measures for reliability cannot be attained through the increasing alignment of theory, design and measurement over time.

The reliability can be claimed through inclusion of low inference descriptors that allow the reader to come to conclusions on their own: recording observations as concretely as possible, using verbatim accounts of people's talk, and reporting data as free of researchers' personal perspectives as possible. These factors are well met in the research here; the observations and verbatim accounts are reprinted for the readers' purpose, even though the step of translation in reporting all excerpts introduces additional challenges to reliability.

I can conclude that the coding procedures through this thesis have been done reliably and informatively; the reliability has been contested and tested through quantitative measures in sections 6.2.2 and 6.4.3. There is good reason to believe the conversations align to the worksheet questions, or that coders *can and have* reliably separated talk that practices good reasoning from talk that is concerned with knowledge and points of view. The validity of lumping various talk features into these interaction themes can instead be contested, as the internal portions of each feature within each category are unknown. This is a threat to the validity of statements about a question type resulting in students practicing areas of an interaction type or practicing all of these things relevant to a skill. This was explored already in section 10.3 in context of the outcomes related to interweaving epistemology and theory.

Of the Conversation Analysis of the selected laboratory session excerpts, the reliability of the findings are a direct measure of the reliability of the transcript. Much care has been taken to prepare the transcripts, but the translation is always also an interpretive step and in this sense, a part of the analysis. The reliability of CA comes from the reader being able to access the same transcribed data and make the same (or different) observations and to confirm the analysis of the researcher. If the data used by the researcher and the reader are different in language, the reliability is in obvious ways – if not by large amounts - undermined. However, there really is not another choice but to translate, if the study is to be read outside of Finland.

10.5.3 Validity

Validity of the results of qualitative research should be assessed through comparing any generalizations against the complete data, analyzing and documenting any deviant cases – in a quote, "using all efforts to falsify our initial assumptions about our data" (Silverman 2001, p. 254).

Suggesting triangularization may not aid in the assessment of validity of a study. Generating data in multiple ways is good in providing a more varied understanding of the problem, but it shouldn't be read as increased objectivity of results - or even necessarily producing a more complete picture (Silverman p. 235). Results are often context bound and using data from a different "context"can simply be incompatible. For example, what is experienced at the lab might indeed be reflected in a learning diary account written right after the lab. However I know that many learning diaries were completed just before turning them in, writing a different account in a different mindset. This is reason why findings should not be uncritically validated through this triangulation: the data are from different contexts.

A complaint against CA and other qualitative research is that its data could be selected and biased to fit an argument. In this thesis I have strived for comprehensive treatment of the data; this means that all data must be incorporated in analysis. Not having transcribed or analysed all of the collected data from the course undermines these claims somewhat. Nevertheless, the choices of data for analysis were not based on a preselection of cases or on a listening through of the tapes. The choices were made based on getting each session and year represented with a few examples. And within those datasets, all generalisations made were tested against all relevant occasions: meaning that they explain all cases unless specifically mentioned otherwise.

What could still have been done to increase the validity of the claims made through CA in this thesis would have been to start with the analysis from a part of the transcripts, and to compare the generalizations from this set against the larger dataset in portions. This was chosen against as the mentions of disciplines within the data set were already spread out thin; and also as the rough transcripts were prepared for the whole dataset, I already had some familiarity with each session, not being able to claim them to be previously unexplored.

The exploration of deviant cases, such as here the single-discipline group of physics student, was utilized in this thesis. Through having studied their talk I can claim with good evidence that the practice in drawing contents from multiple disciplines is not a product of the group composition but a part of the laboratory task design. This data also showed me the effect of students' expertise already in several subjects; and through this insight, it is clear that the categorization of group members as disciplinary experts was not necessary to students who themselves possess the task-relevant knowledge in more than one subject. The data both helped explain other findings as well as alleviate concerns of hand-picking the nicest, most interdisciplinary cases for analysis (Silverman p. 240-241).

10.6 Reflections on the ethics of this study

Did the students' participation in this study withhold them from other possibilities? With the premise of the study being that all students taking the course would do the same things regardless of whether they partook in the study, they did all receive equal treatment.

Possible harms to the students caused by the study existing in the first place would be related to the data collection. The students carrying tape recorders around was possibly mildly annoying, but in the group conversations the recorders were mentioned in passing moments, reminding someone to keep hold of it. The setting up of cameras and recorders and photocopying student worksheet answers did give me less time between the labs to talk with the students in a relaxed environment.

The students who did not participate in the study told of their non-participation so late in the course 2012 that they had already been assigned in the lab groups. It would have been the right call anyway to ensure that they, too, could study in varying group compositions, even though it meant directly that less group data was available for me to study. I was advised by senior staff to ask the students to stay in the study anyway or to request permission to use the tapes, but I took the conservative position of not trying to affect the students' decision in any way and not to use data on them collected thus far – this decision goes further than the requirements of the Finnish National Board of Research Integrity, where it is stated that the data collected up until the moment of permit withdrawal could be used for a study (Finnish National Board of Research Integrity (TENK) 2018).

Benefits of participating in the study were more concentrated on other students than the ones participating: the findings being used to inform development of the course. Perhaps the students who participated in one-on-one interviews about their answers and the Nanoscience programme did come across questions they would not otherwise have pondered, which could have helped them in their later studies. No such effects were tracked down in terms of this study.

Some of the students who were recorded and whose talk was the data for this study and a few conference presentations between 2012 and today have continued their studies and I have run into a few informally in work settings – organizing an outreach project. Without prompting from me, they told that they have found conference abstracts with excerpts of their own talk and that they've followed up on the research through Google searches every now and then. To be a subject of such a study seemed to be amusing to them in retrospect. The participation in the study was clearly memorable to these students.

I believe that for anyone who has not been in the same group, in the course, it would not be possible to recognize a single student from the excerpts in this thesis. I have kept the disciplinary identities as they were (to change them would require heady content editing of the excerpts as well, and could change the nature of the conversations considerably) but masked student names, and where possible, omitted or swapped gender pronouns. Real names of the students, TA:s and the initially interviewed researchers and graduate / master students have been replaced with pseudonyms. The privacy of participants and their expressed opinions is protected in this manner.

10.7 Closing discussion and personal remarks

The single most striking thing about this research to me was the difficulty it posed to students to function in a situation where different disciplinary explanations or approaches were there for choosing. Understanding the nuances of these discussions would not have been possible without using Conversation Analysis; and now the struggles that the students had in these situations are documented. It raises the question of when or where these difficulties turn into a natural ability; possibly some of the difficulties never disappear, particularly if – such as the student panellists suggested – there is no need for collaboration in their area.

The improved design of the laboratory course at hand will help the future nanoscience students to fare better in these situations. I assume being informed about these findings and the exercises students are undertaking to combat the "disciplinary egocentrism" would be helpful also to researchers or students further in their studies who would be interested in doing interdisciplinary work. The activities that promote noticing disciplines or interdisciplinarity can be sorted out from the data – they are the Recall type questions as well as the work around equipment and experimentation, and this knowledge in turn could be used to prepare or improve the contents of other interdisciplinary courses or training sessions. That is, if the goal of these courses or sessions closely aligns with this, i.e. the recognition of disciplinary cultures and practises, which is a strong prerequisite of the ability to swap between disciplinary perspectives.

Laboratory work and its efficiency in teaching science content knowledge is sometimes – rightly so and supported with vast evidence – contested (Abrahams & Millar 2008). The goals of laboratory work are set too narrowly if it is viewed as a vehicle of acquiring content knowledge. As Reid and Shah (2007) show for university chemistry learning, the aims and objectives can and should include the skills for groupwork, and this study offers data on how and where during the experimental sessions these skills are developed – particularly at the points of students working with equipment, measurements, and set-ups. The linkage between this core element of experimental science with its power for practising scientific team work could be a part of any laboratory group work design. This study shows that with a short priming discussion about the importance of group work, the laboratory groups became a fruitful practise area of science teamwork and collaboration.

I see this thesis as having possibility to inform laboratory teaching at the university level throughout science subject, and to some extent, also in high schools. As the Finnish upper secondary school system is introducing courses that are multidisciplinary and phenomena-based, some of the difficulties of students in this nano-course would be informative for teachers planning courses in another combination of subjects for a slightly younger audience.

The difficulties faced in the course should not be read as an indicator of an interdisciplinary topic or context being too difficult or impossible for students to work in. The price to pay of socializing into singular norms and traditions of a discipline – often including the distrust of other disciplines (Hey et al. 2009) – is too high when the future of the university is increasingly interdisciplinary (Newell 2010). If the industry and labor require persons who "understand, use, and integrate knowledge and methods as well as collaborate with disciplinary teams across industry sectors and cultures" (Repko 2012) – people who work in diverse teams of "basic scientists, clinicians, specialists with a background of managing clinical trials, financial analysts, and marketing specialists" (Jacobs 2013) – having even a small portion of the relevant skills upon entrance to working life will be a huge asset to the student of today.

The findings of this study pose an interesting possibility for comparisons of students as beginners in an interdisciplinary context and researchers entering an interdisciplinary research field. With an expected difference in the depth of cognitive, discipline-relevant knowledge and theorizing skills, how does that reflect on the differences that the first-year students and experienced researchers have upon entering an interdisciplinary collaboration? There are very limited findings about students' experiencing interdisciplinary studies in the sciences, as most concentrate on older students or junior researchers. The findings in this thesis stand out in this regard and open up this phase of the interdisciplinary researcher – the very beginner's phase – for further study.

10.7.1 Personal remarks

Teaching on the course was an interesting first-hand experience of having no PCK in many areas, and then discovering some. Personally, I was well acquainted with the PCK in physics, but completely out of the ballpark with chemistry and biology. On a course like this, where the focus was not so much on learning new science content rather than learning how to integrate and use preexisting science knowledge within a group, this was slightly less harmful than it would otherwise have been. But there were many instances where our PCK just fell very short.

For example, a struggle unexpected to me in students trying to approach the gold nanoparticle synthesis as a reversible reaction (seems like reversibility is expected by students when they only see structures of the initial molecules in the worksheet, and do not imagine the lump of gold that forms). In my defense, I did ask a colleague from the Chemistry department if the students would be familiar in working out this redox reaction and they said "sure"! I was so taken by surprise in the first Gold Nanoparticle lab session, when the student groups all came asking about details of this reaction, that after some beating around the chemical reaction bushes I actually said it to them, too – works as evidence that I never claimed to possess chemistry knowledge:

T:	I asked about [this issue] from some chemists that I know and they said *sure* [the students] will be able to figure it out.
Student:	Ya think so? ((laughing))
T:	But I don't have a lot of background in chemistry myself so therefore too I don't wanna say much more about it.

10.7.2 The current state of the Nanoscience and technology course

While the completion of design cycle – particularly its analysis phase – has taken quite more time than intended, the course has been yearly delivered since 2012. The laboratory parts have remained more or less intact (partly as I've waited for the opportunity to engage in the analysis and complete it), but the whole group sessions outside the lab have seem some changes. As laboratory session teachers we have become much more adept at seizing the opportunities to discuss the disciplines and interdisciplinary topics with the students; from overhearing half a sentence, we have a good idea of which task and which interpretation the group is tackling.

In 2014, a task to investigate a nano-related real wold problem was introduced, and in 2015 a role playing task was strapped along its side. The tasks have been about colloidal silver as a supplement (driven by a scandal first in Sweden and later, Finland), a research methodology scandal of imaged stripy gold nanoparticles and the validity and scarcity of evidence for Smart Flare signals coming from inside the cell nuclei. This mirrored the ideas from project IRRESISTIBLE to a great extent – the introduction of Responsible Research and Innovation into the course, but so far, without a mention of the term.

In 2017, the grading system for this course was changed from Pass-Fail to a number grade, causing severe difficulties to the teachers – the difference in outlook is grand. From individual, supportive written feedback we went to rubrics and percentages with no written feedback. The grading logic and purpose will be receiving much attention from us in the following year(s) to ensure the grades are linked to the desired course outcomes rather than something easy to evaluate but irrelevant.

The course is currently co-taught by myself and nano-bioscience researcher Heini Ijäs from University of Jyväskylä & Aalto University, and it remains a compulsory part of the nanoscience candidate degree studies.

YHTEENVETO

"Ala ny sooloilemaan siinä!" Poikkitieteellisen oppimiskokonaisuuden suunnittelu ja analyysi yliopiston nanotieteiden kurssilla

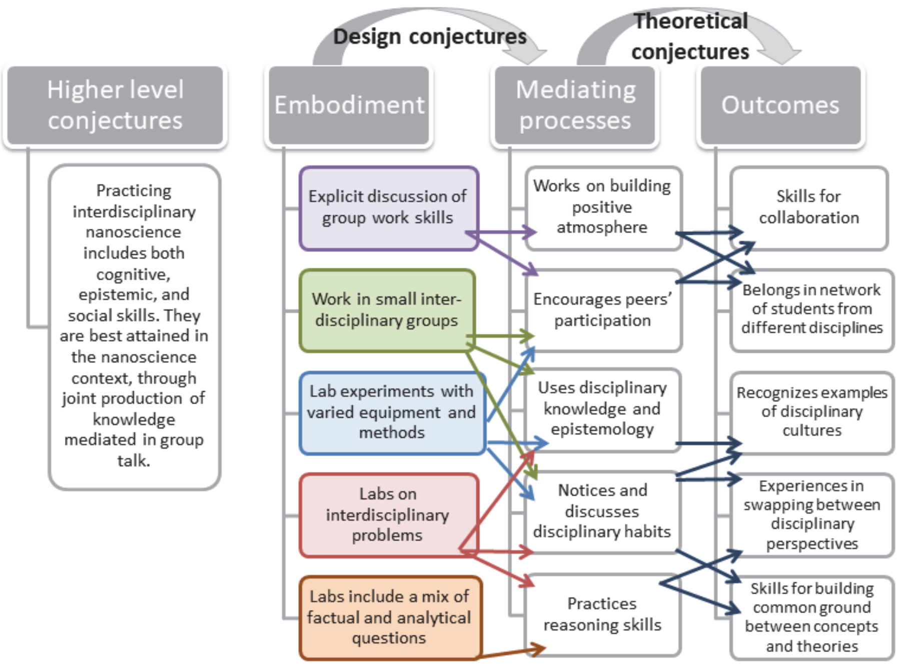
Väitöstyön tarkoituksena oli suunnitella nanotieteiden ja –teknologian kurssi ensimmäisen vuoden opiskelijoille Jyväskylän yliopiston nanotieteen koulutusohjelmassa, joka on käynnistynyt vuonna 2007 ja johon toivottiin lisää nanotieteisiin sitouttavaa sisältöä jo ensimmäiselle opiskeluvuodelle. Kurssin suunnittelua tukemaan valittiin tutkimuksen muodoksi design-tutkimus. Toteutusympäristön analyysissä selvitettiin kurssin keskeisiä reunaehtoja, laajuutta sekä aihevalintoja perustuen paikalliseen koulutustarjontaan sekä muiden suomalaisten yliopistojen tarjoamaan nanotieteiden opetukseen. Lyhyt survey-kysely muiden yliopistojen ja teknisten yliopistojen tarjonnasta selvitti, että varsinaista koulutusohjelmaa ei Jyväskylän lisäksi tuolloin tarjottu, vaikkakin yksittäisiä kursseja nanotieteitä tukevista sisällöistä yliopistoissa järjestettiin. Jyväskylän yliopiston tarjoamassa koulutusohjelmassa nanotieteiden opinnot on järjestetty siten, että opiskelija opiskelee laajasti sekä fysiikkaa, kemiaa että biologiaa ja pienen määrän muita valitsemiaan aineita, esimerkiksi matematiikkaa ja tietotekniikkaa, sekä sen lisäksi joitakin yhteisiä, poikkitieteellisiä kursseja. Kandidaattitutkinto-ohjelmassa yhteisiä kursseja oli tuolloin tarjolla vain yksi itse tutkielman lisäksi, ja opiskelijan hyötyä ajatellen oli olennaista, että poikkitieteellinen työ sekä eri oppiaineiden tietojen väliset suhteet tulisivat tutuksi jo alkuvaiheessa. Kurssin aihealueet suunniteltiin tukemaan myöhempien yhteisten nanotieteen kurssien teemoja sekä Jyväskylän yliopiston nanotieteiden tutkimusaiheita.

Varsinainen ongelma-analyysi työssä keskittyi poikkitieteellisen työskentelyn vaatimuksiin ja poikkitieteellisen opetuksen tavoitteiden rajaamiseen. Aihepiiriin tutustuttiin sekä poikkitieteellistä tutkimusta yleisesti käsittelevän kirjallisuuden myötä että tarkemmin juuri poikkitieteellisiä luonnontieteitä käsittävään tutkimukseen perehtymällä. Niistä nousseita suosituksia opetukselle olivat tieteenalan kulttuuriin mukautumisen tunnistaminen, poikkitieteellinen opiskelu yksittäisten tieteenalojen opintojen rinnalla, yhteistyötaitojen ja viestintätaitojen harjoittaminen, sekä episteemisten ja tiedollisten taitojen keskittäminen poikkitieteellisen työn tarpeisiin, erityisesti tieteenalojen väliseen työskentelyyn. Viimeisellä viitataan erityisesti eri alojen epistemologian ja menetelmien tuntemukseen sekä eri alojen teorioiden tai käsitteiden välisten mahdollisten ristiriitaisuuksien käsittelyyn ja yhdistämiseen.

Ongelma-analyysin osana toteutettiin myös pieni asiantuntijahaastattelu paikallisten nanotieteen tutkijoiden sekä nanotieteen opiskelijoiden keskuudessa. Tavoitteena oli kartoittaa millaisia tavoitteita ja taitoja he näkisivät tärkeänä nanotieteen opinnoissa ja mikä heille oli ollut erityisen hyödyllistä tai haastavaa. Kumpikin ryhmä nosti puheeseensa kirjallisuuskatsauksesta esiin tulleita asioita, kuten yhteistyössä kohdattuja haasteita, tieteenalakohtaisen osaamisen tarpeet, laboratoriotyöskentelyn taidot, sekä ryhmiin kuulumiseen liittyviä pohdintoja.

Näistä ongelma-analyysin osista tutkimuksessa jatkettiin oppimiskäsityksen rajaamiseen työn aihepiiriin sopivaksi; tässä tutkimuksessa oppiminen käsitetään ryhmässä ja keskustelussa tapahtuvaksi tiedon yhdessä luomiseksi, sosiokonstruktiivisen oppimiskäsityksen mukaisesti. Opetuskokonaisuutta ajatellen tässä vaiheessa tarkasteltiin erityisesti ryhmässä työskentelyä ja poikkitieteellisiä taitoja harjoittavia keskustelun muotoja ja etsittiin niistä oppimista edistäviä toimintoja, joita pystyttäisiin kurssilla havainnoimaan. Sellaisia olivat erityisesti ryhmässä työskentelyä ohjaava puhe, jossa kannustetaan ryhmätovereita osallistumaan sekä rakennetaan keskustelua edellisten puheenvuorojen päälle; ryhmän ilmapiiriä luova puhe, jota vahvistetaan esimerkiksi hauskoilla kertomuksilla ja yhteisellä naurulla; päättelyyn ja perusteluun liittyvä puhe, joka avaa opiskelijoiden päättelyketjuja toisille; sekä tieteenalakohtaiseen tietoon liittyvä puhe, johon kuuluu niin asiantuntijaroolin ottaminen faktoja keskusteluun tuomalla kuin myös tarkasteltavan näkökulman tai validiteetin neuvottelu.

Kurssin runko sekä sillä käytettävät oppimateriaalit suunniteltiin nyt näiden pohjustavien analyysien mukaisesti hyödyntäen työssä olettamakarttaa; kartan tarkoitus on kuvata työlle asetettujen tavoitteiden, tavoitteen saavuttamiselle välttämättömien toimintojen, sekä toimintoihin ohjaavien toteutusten välistä suhdetta. Suunnitteluolettamat sekä oppimiskäsitykseen liittyvät teoreettiset olettamat johtavat siten toteutuksista toimintoihin sekä toiminnoista tavoitteisiin, kuten on kuvattu alla.



Tämän työn keskiössä oli erityisesti toimintojen saavuttamisen toteennäyttäminen, sekä niiden myötä myös tavoitteiden saavuttamisen tarkastelu. Kuten design-tutkimukselle on tyypillistä, tosimaailman ympäristössä toteutetulla oppimisjaksolla tavoitteiden saavuttamiseen voi vaikuttaa tuhansittain erilaisia asioita; on mahdotonta näyttää yksikäsitteisesti että vain ja ainoastaan suunnitellut toiminnot johtaisivat tavoitteisiin, jotka nekin ovat moniulotteisia ja vaikeasti mitattavia. On tarkoituksenmukaista keskittyä osoittamaan toimintojen näkyminen kurssilla; hyvin perusteltu suunnittelu- ja teoriaoletusten ketju on riittävä näyttö sille, että kurssi vastaa tällöin tavoitteitaan.

Vuosien 2012 ja 2013 kurssien opiskelijat kahta lukuunottamatta osallistuivat tutkimukseen ja heidän tuottamaansa aineistoa kurssilla käytetään tutkimuksen lähteenä. Myös opiskelijoiden kirjallisesti tuottamaa aineistoa kerättiin, mutta tässä väitöstyössä analysoin vain opiskelijoiden käyttämiä laboratoriotyön lomakkeita sekä heidän keskustelujaan laboratoriotyöskentely-ympäristössä.

Tutkimuksen menetelminä hyödynnettiin sekä temaattista sisällönanalyysiä työlomakkeista sekä opiskelijoiden keskusteluista, että keskustelunanalyysiä rajatusta kokoelmasta keskusteluja, niistä katkelmista, joissa mainitaan joitakin tieteenaloja. Lopulta työhön litteroitiin karkealla, sanatasolla 14 laboratoriotyöskentelyn ryhmätyötä, n. 3h mittaisia kukin, sekä tarkasteltiin keskusteluanalyysiin sopivan tarkan litteroinnin (Jeffersonin merkistöä käyttäen) avulla seitsemän keskustelukatkelmaa, jotka edustavat eri tapoja tieteenalojen esiin nostamisessa. Sisällönanalyysissä käytettyjen eri koodausten luotettavuutta tarkasteltiin käyttäen kahta tai kolmea vertaiskoodaajaa kullekin menettelylle ja tutkimuksessa käytetyille koodauksille saavutettiin kohtuullinen tai hyvä luotettavuuden taso.

Tuloksista käy ilmi, että työssä hyödynnetyt työohjeet vastasivat asetettua suunnittelutavoitetta kysymystyyppien monipuolisuudesta erityisesti siten, että ne sisälsivät sekä tietämisen tasoa aktivoivia ”faktakysymyksiä” että analyyttisempiä, pohdiskelua ja perusteluja vaativia kysymyksiä. Kukin työohje sisälsi erilaisen jakauman kysymysten tarkempia alalajeja, mutta jakauma tietämiseen, tiedon hyödyntämiseen ja tiedosta päättelemiseen liittyviin kysymyksiin oli samankaltainen jokaisessa neljässä laboratoriotyössä.

Opiskelijoiden käymistä keskusteluista tarkasteltiin sitä, kuinka työohjeen erilaiset kysymykset tuottivat eri tavoitteisiin liittyvää puhetta. Tietyt kysymystyypit osoittautuivat erityisen hyödylliseksi näiden tavoitteiden saavuttamisessa; esimerkiksi Muistamista sekä Yhteyksien tunnistamista vaativat matalan tason kysymykset olivat erityisen soveltuvia tieteenalakohtaisen tiedon tarjoamiseen sekä oikean näkökulman etsimiseen. Vastaavasti tiedosta päättelemiseen liittyvät kysymykset sekä tarkemmin Selitä- ja Tulkitse-tyyppiset kysymykset olivat hyödyllisiä päättelykykyä hyödyntävän keskustelun aikaansaamisessa. Näitä yhteyksiä työssä haarukoitiin hyödyntämällä päällekkäisyysanalyysiä tehdyistä koodauksista.

Keskusteluanalyysin avulla havaittiin opiskelijoiden pitävän tieteenaloihin liittyvien seikkojen tunnistamista merkityksellisenä taitona sekä hakevan vertaisilta tunnustusta tästä taidosta. Kömmähdykset toisten opiskelijoiden luokittelussa oikeisiin pääaineisiin tuottivat keskustelussa hämmennystä, joskin kun kurssi oli edennyt pidemmälle ja työtavat tulleet tutummiksi, he pystyivät nauramaan tällaisille tilanteille. Opiskelijat vetosivat toistensa asiantuntijuuteen niissä oppiaineissa, joita tunnistivat tehtävän vaativan, kun heillä ei itsellään ollut tietoja tai taitoja vastaamiseen. Tällaista asiantuntijastatuksen nostoa omasta oppiaineeestaan opiskelijat eivät kuitenkaan harrastaneet, vaan ennemminkin esittivät naureskelevia tai vähätteleviä kuvauksia itsestään tietyn tieteenalan edustajana. Myös tutkimustehtäviä ja niiden osia opiskelijat tunnistivat tiettyyn oppiaineeseen liittyviksi. Tilanteissa, jotka poikkitieteellisten taitojen oppimisen kannalta olisivat erityisen hedelmällisiä – eli kun tehtävä osoittautui liittyvän kahden tieteenalan tietoihin ja tuotti haasteita tulkinnassa – opiskelijat eivät pystyneet neuvottelemaan, vaan ohittivat tilanteet ja niiden epämukavuus näkyi keskusteluista. Tällaisten tilanteiden hyödyntäminen oppimiskokemuksena olisi vaatinut opettajan huomion tai mahdollisesti tarkempaa ohjausta oppimateriaalin mukana.

Kurssin olettamakartassa kuvaillut tavoitteet saavutettiin lukuunottamatta oppiaineiden näkökulmien välillä vaihtamisen kokemuksia. Näiden tilanteiden haastavuus oli kurssin sekä vastaavien, poikkitieteellisten oppimistilanteiden suunnittelua ajatellen merkittävä löydös.

Laboratorioympäristön merkitys poikkitieteellisten taitojen opiskelussa havaittiin tässä työssä kuten aiemmissakin aiheen tutkimuksissa. Nyt erityisesti ryhmän huomioimisen ja kannustamisen sekä hyvän ilmapiirin luomiseen liittyvä puhe kukoisti laitteilla työskennellessä sekä työohjeiden keittokirjamaisia osuuksia suorittaessa. Siis myös tämäntyyppisillä osuuksilla on paikkansa laboratoriotyössä oppimisessa; vaikkakaan ne eivät tehokasta sisältöoppimista vastaavalla tavalla edistä, ne ovat merkityksellisiä sosiaalisten oppimistavoitteiden harjoittelussa, kunhan nämä tavoitteet vain on tuotu myös opiskelijoiden tietoon. Laboratoriotyöskentely voi täyttää hyvin laajan kirjon erilaisia oppimistavoitteita.

Kurssin suunnitteluprosessi täytti ainoastaan yhden design-tutkimuksen mukaisen syklin, ja syklin mahdollinen jatko olisi kiinnostava toteutettava tässä tutkimuksessa esitetyillä pienillä parannuksilla. Kurssi on vastannut sille asetettuja tavoitteita ja se on nyt osa Nanotieteiden kandidaattitutkinnon opetusohjelmaa. Kurssin muotoa, tavoitteita ja oppimateriaaleja on mahdollista saattaa myös muiden nanotieteiden opetusta tarjoavien yliopistojen käyttöön. Tutkimuksessa tehtyjä havaintoja poikkitieteellisistä opetustilanteista ja ryhmäkeskusteluista voidaan soveltaa myös muuhun kuin luonnontieteiden poikkitieteelliseen oppimiseen. Ensimmäisen vuoden opiskelijoiden toimintaa poikkitieteellisessä oppimisympäristössä ei ole usein havainnoitu, vaan tutkimukset ovat keskittyneet tohtorikoulutukseen tai poikkitieteelliseen työympäristöön tuleviin tutkijoihin. Siksi tämän työn löydökset antavat kiinnostavan vertailupohjan oppimisen eri vaiheissa tapahtuvaan tieteenalaan sitoutumiseen sekä opiskelijoiden ja tutkijoiden kohtaamien poikkitieteellisen työskentelyn haasteiden vertailemiseen.

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APPENDIX 1: THE COURSE WORKSHEETS

Nimi: ___________________________________ Aloitus klo: _________________________

Ryhmän muut jäsenet: ____

Elektroforeesi

Tässä työssä tutustutaan elektroforeesiin eli erotustekniikkaan, joka perustuu varautuneiden molekyylien liikkeeseen sähkökentässä. Tämän avulla voidaan erotella esimerkiksi erimittaisia DNA-pätkiä tai muita proteiineja. Yleisesti biokemiallisissa töissä käytetään geelielektroforeesia, jossa tutkittavat partikkelit kulkevat väliaineessa. Tässä työssä väliaineena käytetään agaroosia, joka on merilevistä eristettyä polysakkaridiseosta.

Aloita työ geelin valmistuksella, koska sen jähmettyminen vie aikaa!

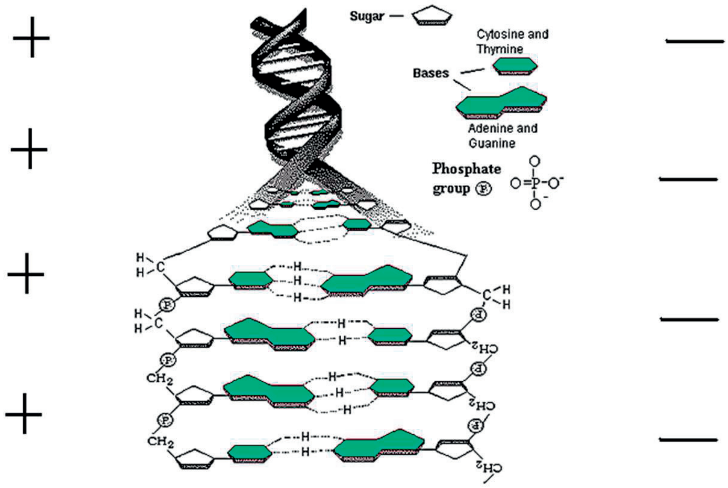
<u>Geelin valmistus:</u>

1. Aseta geelikelkat valutelineeseen siten, että musta raita tulee kamman kohdalle (tämä auttaa erottamaan kammiot näytteitä pipetoidessa).
2. Punnitse 0.8g agaroosia 100ml:n erlenmeyerpulloon. Mittaa ja lisää pulloon 80ml 1xTAE-puskuria. 0.8g agaroosia/80ml puskuria => 1% agaroosigeeli.
3. Kuumenna liuosta mikroaaltouunissa välillä sekoittaen, kunnes seos on täysin kirkasta. Seos kiehuu helposti yli. **Varo** polttamasta käsiäsi kuumaan lasiin! Voit käyttää esimerkiksi käsipaperia käsiesi suojana.
4. Seoksen hieman jäähdyttyä lisää EtBr-liuosta siten, että loppukonsentraatioksi tulee 0.4μg/ml. EtBr-liuoksen konsentraatio on 2mg/ml. **Laske tarvittava määrä EtBr-liuosta!** *EtBr sitoutuu DNA:n ja fluoresoi UV-valossa. Näin voimme ajon jälkeen tutkia DNA:n ajautumista UV-valon avulla.*

5. Kaada valmis liuos geelikelkkoihin valutelineessä. **Varmista**, että seos levittyy tasaisesti kelkkoihin ja että kamman piikit peittyvät seokseen. Ota mahdolliset ilmakuplat pois geelistä esim. kynänkärjellä.
6. Anna agaroosin kiinteytyä rauhassa.

Vastaa agaroosin jähmettyessä seuraavan sivun kysymyksiin DNA:n vuorovaikutuksesta sähkökentän kanssa.

Alla on kuva DNA:sta ja elektroforeesilaitteen varausjakaumasta. **Piirrä kuvaan sähkökentän kenttäviivat ja merkitse mihin suuntaan DNA kentässä ajautuu.**



Mihin osaan DNA:ssa sähkökenttä vaikuttaa?

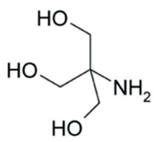
Työssä käytetään koirien parvoviruksesta eristettyä DNA:ta ja DNA on monistettu PCR-laitteella miljardikertaiseksi. Näytteet A, B ja C ovat kukin monisteita viruksen eri geenien alueilta. Ns. restriktioentsyymi, entsyymi, joka katkaisee DNA-juosteen tietyn emäsparisekvenssin kohdalta, on pilkkonut kunkin näytteen DNA:n palasiksi. Näitä entsyymejä on saatavilla useita. Kun valitaan entsyymi, valitaan sekvenssi, jonka kohdalta se pilkkoo DNA-juosteen. **Mikä määrää näytteessä olevien palasten pituuden?**

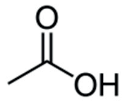
Agaroosin jähmettyessä se muodostaa huokoisen geelin. Agaroosin ja puskurin suhdetta vaihtelemalla saadaan erilaisia ajogeelejä. **Kuinka agaroosigeelin %-pitoisuus vaikuttaa ajettavien partikkeleiden etenemiseen geelissä?** Voit selventää vastaustasi piirtämällä mallin DNA:n juosteiden etenemisestä kahden erilaisen geelin sisällä.

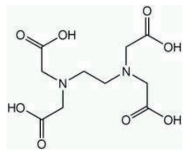
TAE-puskuriliuos sisältää Tris(hydroksimetyyli)aminometaania eli lyhyesti tris-emästä, etikkahappoa ja etyleenidiamiinitetraetikkahappoa eli EDTA:ta. Puskuriliuos toimii ajopuskurina ja on osa ajogeeliä estäen sähkökentän aiheuttamia pH muutoksia. **Miettikää ryhmässä, mitä puskuriliuos tarkoittaa ja miksi sitä tässä työssä tarvitaan?**

Tris Etikkahappo

EDTA







Puskuriliuos myös erottaa DNA-hapot toisistaan ja estää DNA:n laskostumisen. EDTA eristää Mg2+ ja Ca2+ ionit sitoutumalla niihin ja siten estää DNaasientsyymin toiminnan, mikä aiheuttaa DNA:n laskostumisen. **Miettikää ryhmässä, miksi DNA:n laskostuminen pyritään estämään?** Voit selventää vastaustasi piirtämällä kuvan laskostuneen ja yksijuosteisen DNA:n etenemisestä geelissä.

DNA:n ajaminen:

1. Aseta kelkka, jossa geeli on elektroforeesilaitteeseen kaivot virtalähteen puolelle.
2. Lisää elektroforeesilaitteeseen 1xTAE-puskuria siten, että kaivot peittyvät puskuriin.
3. Valmista näytteet: Pipetoi 25µl näytettä ja 5µ 6x latauspuskuria sille varattuun säiliöön. *Pipetoidaksesi paina ensin painonappi ensimmäiseen pysähdykseen, tämän jälkeen upota kertakäyttöinen kärki nesteeseen ja päästä painonappi* ***hitaasti*** *ylös. Lopuksi paina painonappi varovasti ensimmäiseen pysähdykseen ja lopuksi aivan pohjaan.*
4. Merkitse näytesäiliöt tussilla ja sekoita niiden sisältö sentrifugin avulla tasaiseksi.
5. Pipetoi näytteet geelin kaivoihin hitaasti, etteivät ne purskahda ulos kaivoista.
6. Pipetoi reunimmaiseen kaivoon kokostandardi, johon näytteiden koko voidaan verrata.
7. Kirjaa ylös näytteiden nimet siinä järjestyksessä, kun olet pipetoinut ne kaivoihin:

Aloita geeliajo asettamalla töpseli seinään vasta, kun **näytteet ja kansi ovat paikallaan**. Paina virtanäppäintä ja valitse ajojännitteeksi 100V. *Latauspuskuri auttaa seuraamaan DNA:n etenemistä geelissä, koska se liikkuu DNA:n kanssa samaa vauhtia.*

Mitkä tekijät vaikuttavat DNA:n kulkeutumiseen elektroforeesissa?

Millä tekijällä on suurin merkitys DNA:n ajonopeuteen? Perustele.

Miten elektroforeesi erottelee eripituiset DNA-pätkät? Mihin tämä perustuu?

Latauspuskurin väriaineiden avulla voidaan seurata DNA:n etenemistä geelissä. Kun DNA:ta on ajettu tarpeeksi kauan, voidaan se kuvata UV valon avulla. Aikaisemmin lisäämämme EtBr eli etidiumbromidi sitoutuu DNA:han ja fluoresoi oranssinpunaisena UV valon alla. Kuvaaminen tapahtuu sille varatussa huoneessa tietokoneavusteisesti. Kun ajo on valmis, pyytäkää ohjaaja viemään teidät kuvaamaan näyte.

Kokostandardi on liuos DNA-jaksoja, joiden pituudet tiedetään tarkasti. Kokostandardit valmistetaan käsittelemällä plasmideja tietyillä restriktioentsyymeillä. Pituudet ilmoitetaan emäspareina basepair (bp). Kokostandardin avulla voidaan arvioida näytteen DNA-jakson pituutta. Esimerkiksi 100bp kokostandardi näyttää viivoja 100 emäsparin välein (100, 200 jne). **Vertaa näytteitä kokostandardiin ja arvioi näytteiden emäsparimäärää.**

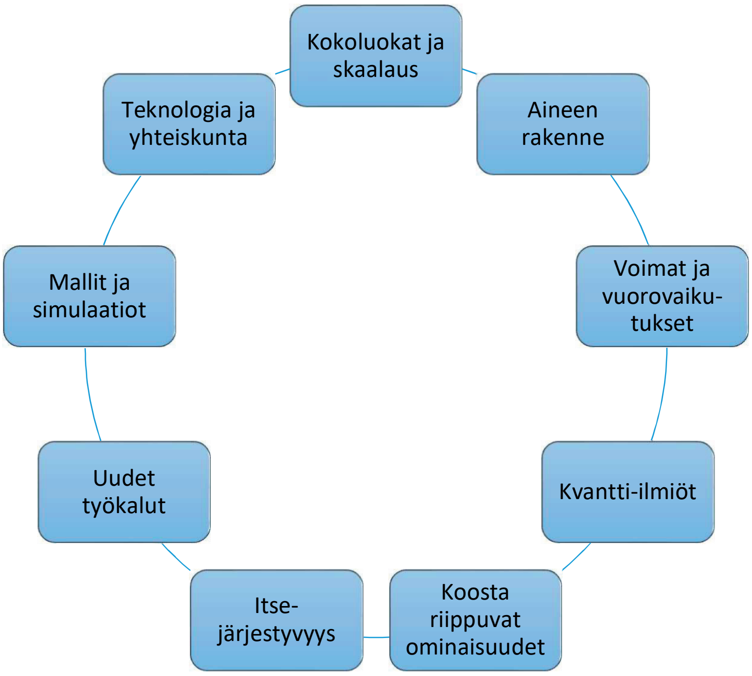
Näyte A:_______bp Näyte B:_______bp Näyte C:______bp

Kuinka tarkasti arvioisit elektroforeesin pystyvän erottamaan emäspareja?

Miksi osa tulostetun kuvan viivoista ovat tummempia kuin toiset?

Miten tällä tekniikalla voisi tutkia, onko jossakin uudessa näytteessä koiran parvovirusta?

Mitä (yhtä tai useampaa) nanotieteen 9. kehysideasta käyttäisitte kuvailemaan elektroforeesia?



Nimi: ___________________________________ Aloitus klo: _________________________

Ryhmän muut jäsenet: ____

Voimamikroskopia

Tässä työssä on ensin kaksi pohdintatehtävää, jonka jälkeen rakennetaan atomivoimamikroskoopin makrokokoinen serkku ja tehdään sen avulla mittauksia.

1.

Tehkää ryhmässä lista asioista, joita valomikroskoopilla voidaan havaita tutkittavasta kappaleesta. Koettakaa kyseenalaistaa itsestään selviltä tuntuvat asiat ja kysykää kustakin asiasta, ovatko ne varmasti havaittavissa mikroskoopilla.

Tehkää toinen lista asioista, joita sormilla tai esim. hammastikulla tunnustelemalla voidaan havaita tutkittavasta kappaleesta.

Kummallakin menetelmällä on alaraja tutkittavan kappaleen koolle. Mikä näissä tapauksissa määrää alarajan eli mittalaitteen resoluution / erotuskyvyn?

a) valomikroskoopille

b) tunnustelulle

Miten tuota alarajaa voisi venyttää nanometrien kokoluokan esineisiin?

2.

Palauttakaa mieliinne kertauksena, mitä tiedätte aiemmista opinnoista atomien välisistä vuorovaikutuksista. Kerätkää ryhmänä vastaukset seuraaviin, apuneuvojen käyttö on sallittua ja muiltakin saa kysyä:

a)

Atomin koko elektroniverhoineen, suuruusluokka _________________

Atomin ytimen koko, suuruusluokka _________________

b) Mihin liittyy / mitä tarkoittaa…

Heikko vuorovaikutus:

Vahva vuorovaikutus:

Paulin kieltosääntö:

c) Keksikää mahdollisimman monta eri käsitettä, jotka kuvaavat atomien sähkövarausten aiheuttamia vuorovaikutuksia atomien tai molekyylien välillä:

d) Jos etsitään vastausta kysymykseen ”Mitä tapahtuu, kun kaksi atomia tuodaan lähekkäin?”, mitkä kaikki kysymyksen 2b ja c käsitteistä ovat tarpeen?

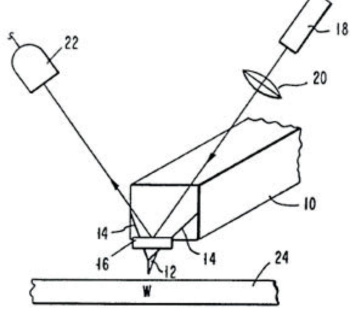
e) Tee tämä tehtävä itsenäisesti (ryhmässä kaikilla voi olla erilainen malli): Minkälainen atomimalli sopisi parhaiten d-kohdan kysymyksen käsittelyyn? Valitse sopiva vanha tai laadi uusi. Piirrä ja/tai kirjoita, selitä piirroksesi osat.

Magneettinen voimamikroskooppi

Rakennetaan magneettinen voimamikroskooppi. Käytettävissäsi on

- valmiita mikroskoopin ”pohjia”, joissa on taipuisa varsi ja magneettinen kärki
- legoja jalustan rakentamiseen
- alusta mikroskoopille ja näytteelle
- teippiä alustan kiinnittämiseksi pöytään
- laserosoittimia
- muovailuvahaa laserosoittimen kiinnitykseen tukevasti
- pyykkipoika tai teippiä laserosoittimen laittamiseksi päälle pidemmäksi aikaa
- millimetripaperia

FIG. 1



Kuva 1. Ensimmäisen atomivoimamikroskoopin patenttihakemuksen kuva mikroskoopin osista. Numeroiden mukaan, 10 – varsi; 12 – kärki; 14 – taipuisa lehtijousi (”cantilever”); 16 – heijastava pinta; 18 – laser; 20 – laserin kohdistus; 22 – valodiodi; 24 – tutkittava näyte.

Ennen kokoamista! Mittauksessa on kolme osaa, josta ensimmäisessä kalibroidaan mittalaite. Kalibroinnin jälkeen mittalaitetta tulee käsitellä **varovasti**; jos laserosoitin heilahtaa muovailuvahassa tai mikroskooppi alustoineen siirtyy pöydällä, kalibraatio ei enää päde uudelle asennolle. Teippaa alusta pöytään ja/tai merkitse teipillä, missä kohdassa pöytää alusta ja mikroskooppi sijaitsevat.

Kootkaa mikroskooppi ryhmässä. Millimetripaperin tarkoitus on korvata kuvan 1 laitteistosta valodiodi; se asetetaan seinälle sopivalle korkeudelle, ja siihen merkitään laserin heijastama täplä mikroskoopilla mitattaessa. Testaa paperin sopivaa sijaintia. Jos muutat mikroskoopin korkeutta, joudut todennäköisesti myös siirtämään paperia (mutta tämä ei vaikuta kalibraatioon).

Työssä tehdään seuraavat mittaukset:

1) kalibraatio

2) kontaktivoiman mittaaminen

3) kaksiulotteisen näytteen tutkiminen

Mittauksissa käytetään Excel-pohjaa, joka tekee laskutoimitukset puolestanne. Pohja löytyy kurssin kotisivulta Kopasta.

Kalibraatio

Hakekaa sinitarraa käytettäväksi kalibraationäytteinä. Sinitarran avulla saadaan kärkeen kohdistettua tunnettu voima. Tehtävänänne on mitata mikroskoopin kalibraatiokäyrä, jonka avulla yhdistetään laserpisteen paikan muutos millimetripaperilla mikroskoopin kärkeä taivuttavaan voimaan.

Lopputuloksena on kuvaaja voima *F* vs. pisteen paikan muutos *x*.

Miksi kuvaajan perusteella taipuisan varren ja kärjen käytöstä voi kuvailla jousen käytökseen sopivalla yhtälöllä?

Kontaktivoiman mittaaminen

Noutakaa y-suunnassa nostettava näyte. Käytetään sitä mallina atomien välisestä kontaktivoimasta.

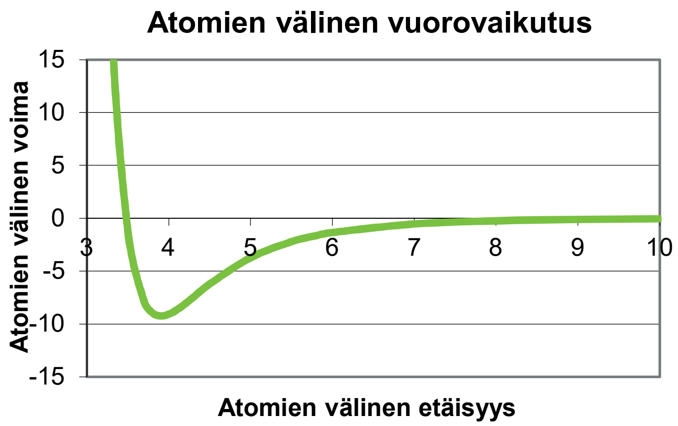
Voimamikroskooppia täytyy nostaa, että näyte mahtuu sen alle. Testaa, että mahdut nostamaan näytettä sopivan mittausvälin verran. Mittauksen aloituskohta pitäisi olla juuri ja juuri niin kaukana näytteestä, ettei mikroskoopin kärki vielä taivu. Mittauksen lopetuskohta tulisi olla niin lähellä näytettä kuin mahdollista, eli vaahtomuovi saa litistyä.

Mitä atomien välisiä vuorovaikutuksia tässä mielestäsi mallinnetaan

a) vaahtomuovilla?

b) magneetilla?

Kun olet tehnyt mittauksen, merkitse allaolevaan mallikuvaan (yksiköt mielivaltaisia) seuraavat kohdat:
A – voima kärjen atomin ja tutkittavan atomin välillä on nolla
B – alue, jossa näyteatomi ja kärkiatomi vetävät toisiaan puoleensa
C – alue, jossa näyteatomi ja kärkiatomi hylkivät toisiaan
D - alue, jossa mikroskooppi ei toimi eli atomien etäisyyden muutos ei näy mittalaitteessa (voi olla päällekkäin edeltävien alueiden kanssa)



Mille etäisyydelle toisistaan kuvan mukaan asettuisivat kaksi atomia, jos ne viedään lähelle toisiaan? Miten päättelit tämän?

Palaa tehtävässä 2 valitsemaasi atomimalliin. Voit tarvittaessa muuttaa sitä tähän tehtävään. Esitä näyte- ja kärkiatomi mallin avulla alueilla B ja C:

B – alue, jossa näyteatomi ja kärkiatomi vetävät toisiaan puoleensa

C – alue, jossa näyteatomi ja kärkiatomi hylkivät toisiaan

2-ulotteisen näytteen tutkiminen

Tässä tehtävässä ryhmät vaihtavat näytteitä keskenään, joten jos olette edellä muita ryhmiä, joudutte odottamaan vähän.

Noutakaa 6 viivotinta ja klemmareita näytteen valmistamiseen. Suunnitelkaa klemmareista näyte viivottimille. Näyte voi esittää kaksiulotteista kuvaa, kun viivottimet ladotaan numerojärjestykseen. **Huom!** pysykää lukemien 3 ja 18 cm sisäpuolella (ks. Excel-taulukko) tai vielä pienemmällä alueella.

Kun näyte on valmis, antakaa se seuraavalle ryhmälle.

Kun saatte tutkittavan näytteen, valmistelkaa mittaus. Laskekaa mikroskooppi sopivalle tasolle (kokeilkaa, voiko viivottimen työntää sen alta ilman, että skooppi napsahtaa kiinni). Merkitkää mikroskoopin lukukohta pohjaan esim. teipillä tai toisella viivottimella, jolloin on helpompi lukea näyteviivottimelta mitattava piste.

Mitä näyte mielestänne esittää? Kysykää näytteen laatineelta ryhmältä, oliko tulkintanne oikea.

Mitkä kaikki tekijät vaikuttavat saadun kuvan tarkkuuteen?

Millaisia ongelmia mittauksessa tai sen valmisteluissa oli? Alleviivaa ne ongelmat, joiden arvelette esiintyvän myös todellisella atomivoimamikroskoopilla mitattaessa.

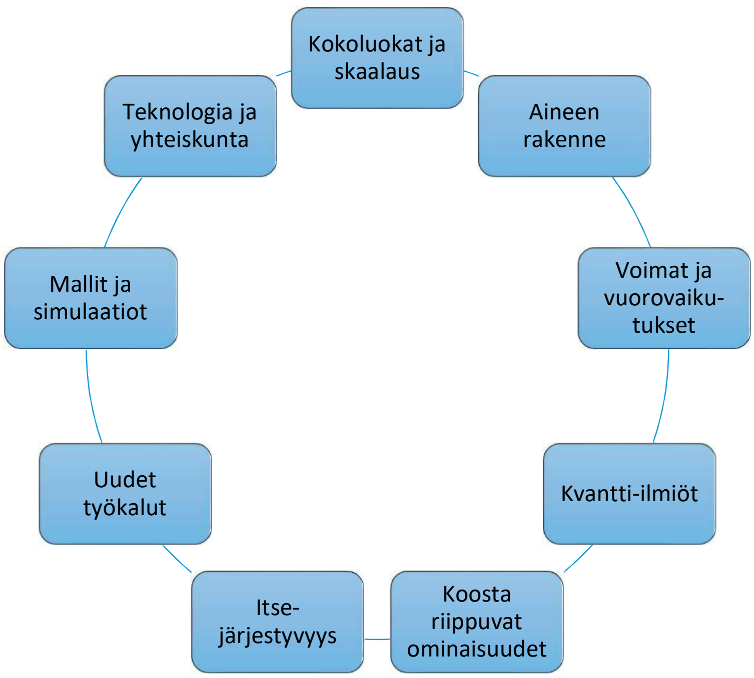
Mieti tuottamaasi 2D-kuvaa ja valokuvaa (tai valomikroskoopin kuvaa).

Miten kuvat eroavat…

- kuvan tekemiseen kuluvan ajan suhteen?

- kuvan sisältämän informaation suhteen?

Mitä (yhtä tai useampaa) nanotieteen 9. kehysideasta käyttäisitte kuvailemaan atomivoimamikroskooppia?



Nimi: ________________________________ Aloitus klo: ______________________

Ryhmän muut jäsenet: ____

Nanohiukkaset ja värit

Tässä työssä pohditaan, miten eri tavoilla syntyy värejä nähtäväksemme, ja mitä tekemistä niillä on nanotieteiden kanssa. Kokeellisessa osuudessa syntetisoidaan nanokultahiukkasia. Sitä ennen työssä on alustus– ja tiedonhankintatehtäviä (tehtävät 1 ja 2).

1.

Tee alkupohdinta ensin itsenäisesti ja vertaa sitten vastauksia ryhmäsi kanssa.

Muistele omistamiasi tai käyttämiäsi tuotteita, joissa oli/on väriä vaihtava osa (esim. Barbie, jonka hiukset vaihtoivat väriä, kun ne kasteltiin kylmällä vedellä). Kirjoita ylös niin monta tuotetta kuin tulee mieleesi.

Jaa tulokset ryhmäsi kanssa. Valitkaa joku esimerkeistänne ja miettikää yhdessä, miten värin vaihtaminen on toteutettu – millaisesta muutoksesta materiaalissa voisi olla kyse? Oikeaa vastausta voi olla vaikea selvittää tarkasti, koska se on usein tuotesalaisuus, mutta joitain mekanismeja tunnetaan yleisellä tasolla.

Esitä ehdotuksenne mekanismista alle, voit käyttää piirrosta apuna:

2.

Ennen yliopistoa opitaan, että esine on jonkin värinen, koska se absorboi tiettyä aallonpituutta ja heijastaa loput. Tämä on tosi mutta hyvin pintapuolinen näkemys väreistä!

Tutustukaa sivustoon http://www.webexhibits.org/causesofcolor

Kunkin ryhmän jäsenen tehtävänä on selvittää yksi ao. kysymyksistä (ympyröi se, jonka selvität itse).

Älä huolestu, jos et ymmärrä täysin sivulla olevaa selitystä; osassa on jo aika syvälle menevää kemiaa, fysiikkaa tai biologiaa mukana. Käykää löytyneet selitykset ryhmässä läpi ja käyttäkää omien pääaineidenne asiantuntemusta hyväksi ja kyselkää muilta ryhmiltä ja ohjaajilta, kunnes arvelette suunnilleen ymmärtäneenne kunkin kohdan.

a) Miksi Morpho-perhonen on kirkkaan sininen?

b) Miten tulikärpänen (*firefly*) valaisee?

c) Mistä kadmiumin (*Cadmium*) keltainen väri tulee?

d) Miten punakaali (*red cabbage*) toimii pH-indikaattorina?

Nanokultahiukkasten synteesi

Työssä tarvitaan seuraavat välineet:

- Erlenmeyer-lasi ja 100ml mittalasi
- sekoitustikku
- keittolevy
- koeputkiteline ja 5 koeputkea
- kertakäyttöisiä pipettejä

Työssä käytettävät kemikaalit ovat ärsyttäviä ja siksi työn aikana käytetään **suojahanskoja.** Ole varovainen kuumentaessasi kemikaaleja keittolevyllä.

Työn vaiheet

Kukin ryhmä kerää tarvittavat aineet työpisteelle, pienet määrät voi kerätä kertakäyttöpipetteihin.

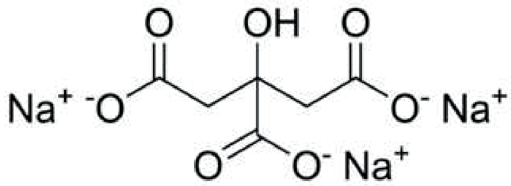
Aine	Kemiallinen kaava	määrä
kultasuolaa (vetytetrakloroauraattia) 10 mMol liuoksena	$HAuCl_4$	1 ml
trinatriumsitraattia 1% liuoksena	$Na_3C_6H_5O_7$	1 ml
ruokasuolaa	NaCl	n. 0,5g
Tislattua vettä	H_2O	100 ml

Trinatriumsitraatti on mm. lisäaine E331-koodilla, se on yksi sitruunahapon suoloista. Kultasuolaa taas saadaan esimerkiksi kun kulta liukenee kuningasveteen.

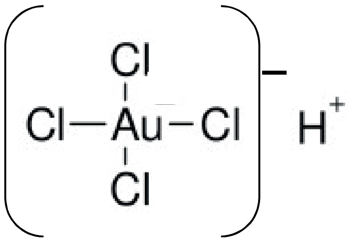
Kumpikin yhdisteistä liukenee helposti veteen. Tässä työssä yhdistetään nämä vesiliuokset keskenään. Alla olevissa rakennemalleissa on kummankin yhdisteen molekyylien rakenne kuvattuna ennen veden lisäämistä. Pohtikaa ja ennustakaa, miten nämä molekyylit käyttäytyvät kuumassa vedessä ja mitä liuokset yhdistettäessä tapahtuu.

Vinkki: Miten näistä syntyisi hapetus-pelkistysreaktio, jonka tuloksena saadaan kultahiukkasia?

Trinatriumsitraatti



Kultasuola



Selitystä ja/tai piirroksia:

Valmistetaan nyt edellä kuvailtuun tapaan eli **Turkevichin menetelmällä** nanokultaliuosta:

Mittaa Erlenmeyer-lasiin 40 ml vettä. Lisää 1 ml kultasuolaliuosta.

Kuumenna neste kiehuvaksi keittolevyllä ja sekoita välillä.

Lisää 1 ml trinatriumsitraattia. Nyt liuosta on sekoitettava jatkuvasti. Anna kiehua rauhallisesti ja sekoita n. 10 min ajan. Ota Erlenmeyer-lasi pois keittolevyltä ja anna seoksen jäähtyä hetken.

Olet valmistanut kultakolloidiliuosta!

Kuvaile liuoksen väriä:

Mitä ”kolloidi” tarkoittaa?

Millaisia voimia liuoksen nanohiukkasten välillä vaikuttaa?

Ennusta, miksi ja mitä tapahtuu, jos liuokseen lisätään ruokasuolaliuosta?

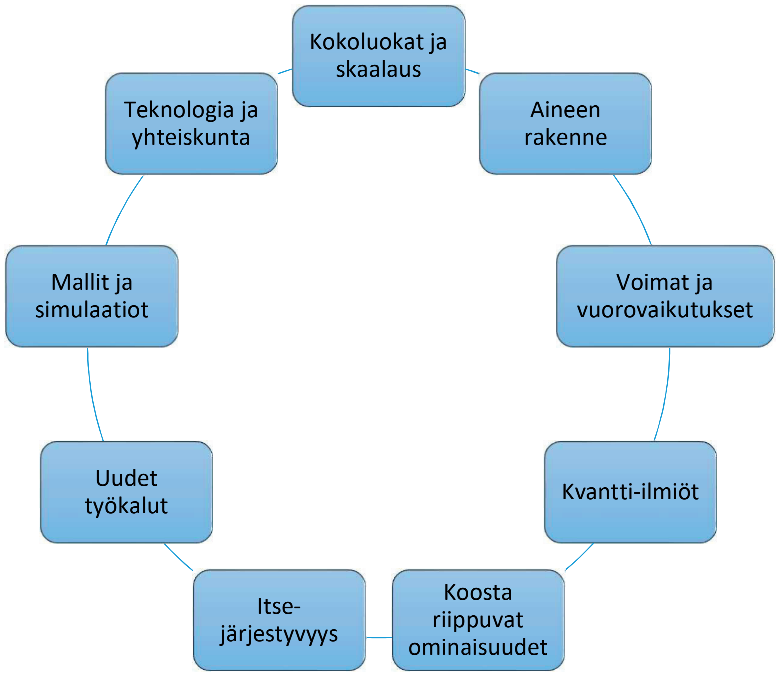
Jaa kultakolloidiliuos tasan viiteen koeputkeen.

Valmista ruokasuolaliuos ruokasuolasta ja n. 10 millilitrasta tislattua vettä. Lisää suolaliuosta pipetillä koeputkiin seuraavasti:

1. koeputkeen ei lisätä mitään
2. koeputkeen lisätään 1-2 pisaraa suolaliuosta
3. koeputkeen lisätään 4-5 pisaraa suolaliuosta
4. koeputkeen lisätään n. 10 pisaraa suolaliuosta
5. koeputkeen lisätään pelkkää tislattua vettä n. 10 pisaraa

Kuvaile liuosten värejä:

Keskustelkaa nyt ryhmässä siitä, miten liuos ja sen nanopartikkelit muuttuivat, kun siihen lisättiin suolaa. Mitä (yhtä tai useampaa) nanotieteen 9. kehysideasta käyttäisitte kuvailemaan tätä ilmiötä?



Tutustutaan vielä tarkemmin nanokultaliuoksen värin syntyyn. Metallisen kappaleen pinnalla tapahtuu jatkuvasti plasman värähtelyjä, ja nämä värähtelyt ovat kvantittuneita. Plasman värähtelykvanttia kutsutaan *plasmoniksi*. Taajuudeltaan ja aallonpituudeltaan sopivat plasmonit muodostavat kappaleen pintaan ikään kuin seisovia aaltoja. Vain tietyt valon aallonpituudet kytkeytyvät näihin plasmoneihin. Kun muut heijastuvat pinnasta, ne määräävät kappaleen havaittavan värin.

Vaikka nanokultahiukkaset ovat paljon valon aallonpituuksia pienempiä, niiden pinnoille sopii plasmoneita, jotka aiheuttavat liuokselle havaittavan värin. Selailkaa näitä kahta artikkelia ja tulkitkaa, mitä värille tapahtuu, kun kaksi nanokultahiukkasta tuodaan lähelle toisiaan:

Optical properties of two interacting gold nanoparticles
W. Rechberger, A. Hohenau, A. Leitner, J.R. Krenn, B. Lamprecht, and F.R. Aussenegg (2003).
Optics Communications, Volume 220, Issues 1–3, p. 137-141.

Interparticle Coupling Effects on Plasmon Resonances of Nanogold Particles
K.-H. Su,Q.-H. Wei, and, X. Zhang*J. J. Mock,D. R. Smith, and, and S. Schultz (2003).
Nano Letters, Volume 3, Issue 8, p. 1087-1090.

Esittäkää lopuksi kattava selitys (siten kuin sen näillä tiedoin ymmärrätte) sille, miksi kultakolloidiliuoksen väri muuttui:

Nimi: ___________________________________ Aloitus klo: ________________________

Ryhmän muut jäsenet: ____

Nanomagnetismi

Tässä tutkimuksessa etsitään yhteyksiä magneettisten kappaleiden käyttäytymisestä nanoskaalassa ja suuremmissa mittakaavoissa. Toisaalta löydämme myös joitakin tärkeitä eroja. Koeta pitää mielessäsi kappaleiden kokoerot, tutkimiesi esineiden ympäristöt ja voimat, jotka kappaleisiin vaikuttavat.

Magneetin valmistaminen

Miettikää ennen työn aloittamista ryhmänä, mitä erilaisia tapoja on havaita magneettikenttä. Kaikkien tapojen ei tarvitse soveltua laboratoriotyöhön, vaan ne voivat esiintyä luonnossa tms.:

Tarvikkeet:

rautajauhetta	sauvamagneetti	sakset
astia rautajauheelle	kuumaliimapistooli + liimaa	
mehupilli	paperia	

Rakennetaan magneetin malli, ns. ”pillimagneetti”. Katkaiskaa mehupillistä n. 10 cm kappale ja pursottakaa kuumaliimaa toiseen päähän tulpaksi. Täyttäkää sitten pillistä n. 3/4 rautajauheella (apuna voi käyttää paperista tehtyä suppiloa) ja pursottakaa kuumaliimaa toiseenkin päähän. Kuumaliiman jäähdyttyä malli on valmis.

Magnetoikaa pillimagneetti vetämällä sauvamagneetin toista päätyä sitä myöten useita kertoja (20+). Laskekaa pillimagneetti varovasti tämän jälkeen paperille.

Miten tutkisitte pillimagneetin magneettikenttää? Toteuttakaa joku ehdotuksista.

Piirrä kuva tutkimastanne magneettikentästä:

Demagnetoikaa pillimagneetti ja varmentakaa tulos tutkimalla magneettikenttää uudestaan. Miten demagnetoitte:

Selitä ja/tai piirrä mahdollisimman tarkasti, miten magnetoitu ja demagnetoitu pilli eroavat toisistaan.

Edellistä vastausta laajentaen: mitä aineelle tapahtuu, kun se magnetoidaan?

Rautahiukkasten tutkiminen

Pohdi seuraavia kysymyksiä ensin itsenäisesti pari minuuttia ja valitse vastauksesi. Keskustelkaa niistä sitten ryhmässä.

a) Voiko rautajauheen siru olla magneetti?

b) Mikä ominaisuus määrää, miten pieni magneetti voi ylipäätään olla?

c) Voiko neste toimia magneettina? Miksi / miksi ei?

Tarvikkeet:

2 muoviastiaa	ruokaöljyä	magneetti (muovipussissa)
rautajauhetta	muovilusikka	kompassi

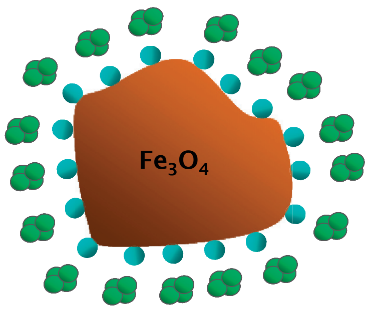
Valmista ensimmäiseen muoviastiaan seos rautajauheesta ja ruokaöljystä. Puolikas muovilusikallinen rautajauhetta ja loraus öljyä riittävät.

Vedä magneettia hitaasti astian pohjaa pitkin siten, että seokseen muodostuu useita vierekkäisiä viivoja. Laita magneetti syrjään ja laske astia pöydälle varoen heiluttelemasta sitä.

Onko rautasiruilla magneettikenttää magneetin poistamisen jälkeen? Kuinka tiedät sen?

Mitä johtopäätöksiä voit tehdä rautajauheen ja öljyn seoksesta havaintojesi ja edellisten vastaustesi perusteella?

Huom! Tässä osassa työtä käytettävä ferroneste tahraa kaiken, mitä se koskettaa. Varo vaatteitasi ja käytä kumihansikkaita. Varaa pöydälle paperipyyhkeitä ja ilmoita heti, jos nestettä läikkyy johonkin.
Älä anna magneettien joutua kosketuksiin nesteen kanssa!



Nouda ferroneste muoviastiassa. Nesteessä on kiinteitä, n. 10 nm pitkiä rautaoksidihiukkasia - kuten rautaviilajauheen sirut, mutta pienempiä - läpinäkyvään öljyyn sekoitettuna. Hiukkasten pinnalla on kerros $(CH_3)_4N^+$ -ioneja, jotka liittyvät rautaoksidihiukkaseen hydroksidi-ionin OH^- kautta.

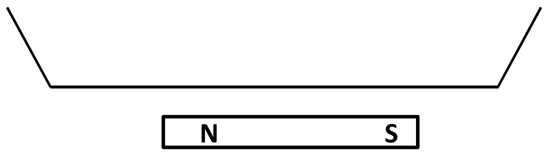
Miten positiivinen pintavaraus hiukkasissa vaikuttaa liuoksen ominaisuuksiin?

Käytä magneettia ja kompassia ja etsi ainakin kaksi eroavaisuutta ferronesteen ja rautaviilajauhon ja öljyn seoksen välillä. Mitä eroja huomaatte?

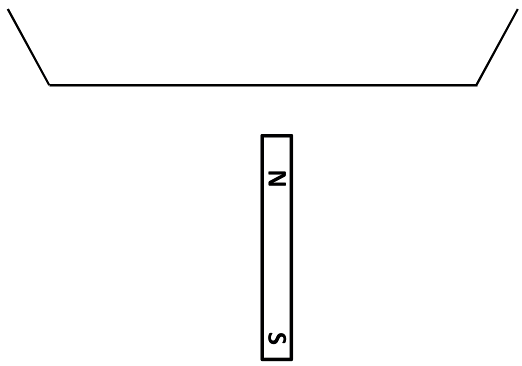
Täydennä kuvat esittämään magneettista nestettä astioissa, kun astian alla on tai ei ole magneettia. Piirrä myös magneetille ne ominaisuudet, joiden avulla voit selittää ferronesteen käyttäytymisen kussakin kuvassa.

a. Ei magneettia.

b. Magneetti on astian alla.



c. Sama magneetti on astian alla, käännettynä pystysuuntaan.



Tarkennetaan vielä, miten rautahiukkasen koko vaikuttaa sen magnetoitumiseen:

Muistele pillimagneettia. Miten sen demagnetoiminen vaikutti rautahiukkaseen, joista pillimagneetti koostuu?

Jos yksi nanokoon rautaoksidihippu, joita ferroneste sisältää, on yhden alkeisalueen suuruinen, arvioi alkeisalueiden määrä isommassa, ruokaöljyyn upotetussa rautahiukkasessa.

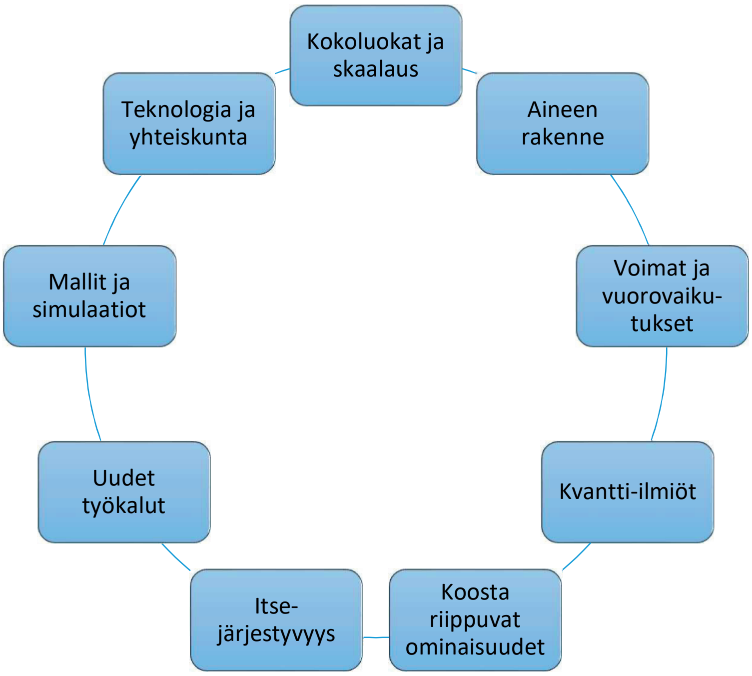
Arvioi seuraavaksi ferronesteen rautaoksidihipun pinnalla olevien molekyylien määrän suhdetta samaisen hipun sisällä olevien molekyylien määrään.

Miten yo. laskelmat auttavat selittämään, miksi ferronesteen hiukkaset käyttäytyvät eri tavalla kuin ruokaöljyyn lisätyt rautahiukkaset, kun magneetti otetaan pois astian läheltä?

Piirtäkää vielä alle kuvaajat (ei tarvitse merkitä numeerisia arvoja, vaan muoto) hystereesistä ferromagneettiselle aineelle sekä kiinteälle rautakappaleelle. Miten edellä kuvaillut ominaisuudet näkyvät hystereesikuvaajista?

Tutustu lopuksi simulaatioon magneettisista hiukkasista. Simulaatio löytyy ohjaajan koneelta. Täydennä mahdolliset aukot edellä simulaatiota tutkittuasi.

Mitä seuraavista 9 kehysajatuksista käyttäisit kuvailemaan ferronesteen käyttäytymistä?



APPENDIX 2: RESEARCH PERMITS

Tutkimus kurssilla SMBP802 Nanotiede ja nanoteknologia

Olet ilmoittautunut tälle kurssille Korpissa. Alta saat lisätietoja kurssiin liittyvästä tutkimusprojektistamme. Lue tämä posti huolella ja vastaa sitten viestiin!

Tutkimuksen tausta

Tutkimuksessa tarkastelemme, miten nanotieteen kandidaattiohjelman opiskelijat rakentavat käsitystään nanotieteistä. Olemme kiinnostuneita siitä, miten opiskelijat hahmottavat nanotieteen käsitteitä ja millaisena he kokevat opiskelun poikkitieteellisessä kandidaattiohjelmassa. Sinua pyydetään osallistumaan tutkimukseen, jotta voimme tutkia tapoja, joilla opiskelijat ajattelevat ja tulkitsevat kurssin aikana esiin tulevia käsitteitä. Tutkimuksesta saamiemme tietojen pohjalta kehitämme seuraavien vuosien kursseja edelleen. Kurssilla käytämme erilaisia opetusmenetelmiä ja siellä on tyypillistä yliopistokurssia enemmän keskustelu- ja ryhmätyöskentelyä.

Tutkimustavat

Kaikista aineistoista, joita käytämme tutkimustarkoituksessa, poistetaan nimesi. Vastauksiasi seurataan vain tunnistekoodin avulla. Tutkimukseen osallistuminen ei vaikuta kurssin arvosteluun tai kurssilla työskentelyyn. Se merkitsee ainoastaan, että saamme lupasi käyttää seuraavaa aineistoa tutkimuksessamme:

Kurssin alussa pidetään ennakkokysely, josta selvitämme, mitä jo tiedät ja ajattelet nanotieteistä. Kun kurssi päättyy, vastaat jälkikyselyyn. Tämä auttaa meitä ymmärtämään, mitkä osat tunneista ovat avautuneet opiskelijoille, ja mitä meidän tulee muuttaa. Ennakko- ja jälkikysely kuuluvat kurssin tehtäviin riippumatta osallistumisesta tutkimukseen.

Kurssin oppimistilanteet videoidaan, jotta voimme palata tilanteisiin analysoidessamme tuloksia. Videoille tallentuvat keskustelut kirjoitetaan osin puhtaiksi. Niiden avulla yritämme selvittää, millaiset tehtävät toimivat parhaiten.

Lisäksi keräämme kopioita kirjoituksistasi, kuten töiden muistiinpanoja ja kurssin kirjallisia tehtäviä. Voimme myös pyytää sinua lyhyeen haastatteluun varmistaaksemme, että tulkitsemme vastauksiasi oikein. Haastattelusta saa myös kieltäytyä. Mahdollinen haastattelu nauhoitetaan ja kirjoitetaan puhtaiksi, että voimme analysoida vastauksiasi tarkemmin.

Osallistumisen kesto

Tutkimus kestää kurssin SMBP802 ajan, yhteensä n. 25 tuntia kontaktiopetusta.

Hyödyt opiskelijalle

Saat oppia nanotieteistä uuden kurssin ja oppimateriaalin avulla. Sen lisäksi osallistuminen haastatteluihin voi auttaa sinua ymmärtämään paremmin oppimiasi sisältöjä. Tulevat opiskelijat tulevat hyötymään tutkimuksen tulosten pohjalta tehtävistä parannuksista kurssiin.

Vapaaehtoinen osallistuminen

Osallistuminen tähän tutkimukseen on vapaaehtoista. Jos suostut tutkimukseen, voit perua suostumuksesi koska vain, eikä se vaikuta tekemisiisi kurssilla tai suoritusmerkintääsi.

Yhteystiedot:

Jos sinulla on kysymyksiä tutkimusprojektista, voit ottaa yhteyttä seuraaviin henkilöihin:

Anna-Leena Kähkönen (anna-leena.m.kahkonen@jyu.fi)

prof. Janne Ihalainen (janne.ihalainen@jyu.fi)

prof. Jouni Viiri (jouni.viiri@jyu.fi)

Vahvistus suostumuksesta

Ole hyvä ja vastaa nyt tähän sähköpostiin ja ilmoita meille osallistumisestasi tutkimukseen. Kirjoita viestiin selkeästi, että haluat tai et halua osallistua yllä kuvailtuun tutkimukseen.

Kiitos!

Anna-Leena Kähkönen

Nanotieteen oppimisen tutkimus kurssilla

Kurssia käytetään tutkimuksessa, jossa selvitetään, miten yliopisto-opiskelijat oppivat nanotiedettä ja miten tällaista poikkitieteellistä opiskelua voidaan kehittää. Tutkimusprojekti alkoi vuonna 2012 ja viime vuoden aineiston pohjalta on jo tehty muutoksia tämän vuoden kurssiohjelmaan. Sinua pyydetään osallistumaan tutkimukseen, jotta voimme tutkia tapoja, joilla opiskelijat ajattelevat ja tulkitsevat kurssin aikana esiin tulevia käsitteitä.

Tutkimustavat

Kaikista aineistoista, joita käytämme tutkimustarkoituksessa, poistetaan nimesi. Vastauksiasi seurataan vain tunnistekoodin avulla. Tutkimukseen osallistuminen *ei vaikuta* kurssin arvosteluun tai kurssilla työskentelyyn. Teet kurssilla samat tehtävät riippumatta osallistumisesta tutkimukseen. Osallistumisesi merkitsee, että saamme luvan käyttää seuraavaa aineistoa tutkimuksessamme:

- Alkukysely ja loppukoe, jotka kuuluvat kurssin tehtäviin riippumatta osallistumisesta tutkimukseen.
- Nauhoitteet kurssin oppimistilanteista. Keskustelut kirjoitetaan osin puhtaiksi.
- kopiot kirjoituksistasi: työlomakkeet ja kurssin kirjalliset tehtävät.
- Voimme myös pyytää sinua lyhyeen haastatteluun kysyäksemme kokemuksiasi kandiohjelmassa opiskelusta ja varmistaaksemme, että tulkitsemme vastauksiasi muissa aineistoissa oikein (esim. alkukyselyssä). Haastattelusta voi kieltäytyä. Mahdollinen haastattelu nauhoitetaan ja kirjoitetaan puhtaaksi, että voimme analysoida vastauksiasi tarkemmin.

Osallistumisen kesto

Tutkimus kestää kurssin SMBP802 ajan.

Hyödyt opiskelijalle

Saat oppia nanotieteistä uuden kurssin ja oppimateriaalien avulla. Sen lisäksi osallistuminen haastatteluihin voi auttaa sinua ymmärtämään paremmin oppimiasi sisältöjä. Tulevat opiskelijat tulevat hyötymään tutkimuksen tulosten pohjalta tehtävistä parannuksista kurssiin sekä kandidaattiohjelmaan.

Vapaaehtoinen osallistuminen

Osallistuminen tähän tutkimukseen on vapaaehtoista. Jos suostut tutkimukseen, voit perua suostumuksesi koska vain, eikä se vaikuta tekemisiisi kurssilla tai suoritusmerkintääsi.

Yhteystiedot:

Jos sinulla on kysymyksiä tutkimusprojektista, voit ottaa yhteyttä seuraaviin henkilöihin:

Anna-Leena Kähkönen (anna-leena.m.kahkonen@jyu.fi)

prof. Janne Ihalainen (janne.ihalainen@jyu.fi)

prof. Jouni Viiri (jouni.viiri@jyu.fi)

Vahvistus suostumuksesta

Haluan osallistua yllä kuvailtuun tutkimukseen. Saan halutessani kopion tästä lomakkeesta allekirjoitettuani sen.

____

Opiskelijan allekirjoitus

_________________________________ _____________________

Nimen selvennys Päiväys

APPENDIX 3: COMPARISONS OF CODING

During the analysis phase, there was a file loss which resulted in loss of parts of the coding. On a whole, the coding of student talk under the dimensions of interdisciplinary group talk had to be re-done from scratch, and some items – combining two categories into one, and including laboratory procedure talk into the analysis – were changed in the process. Also a four transcriptions were lost and had to be re-done, including the analysis of talk related to each question type, the disciplines. In addition the question type coding was lost from two transcripts.

What remained from the first round was the chart of frequencies and C-coefficients of the body of transcripts that was finished with analysis at the time, FIGURE 1. Because there was no way to establish how many transcripts were fully coded and included in this chart, it doesn't make sense to compare the frequencies against the ones in this thesis. Some support for the coding choices can be made by comparing the C-coefficients for dimensions of Reasoning (here under working name "argument") and Knowledge.

The c-coefficients that were very prominent initially were Affective dimension and disciplines; the Reasoning dimension and question types Interpret information, Use models, and Draw conclusions, Formulate questions, and Analyse; the Knowledge dimension and question types Explain, Use models, Provide examples, Recall, Analyse and Formulate questions; and Peer dimension with Provide examples and Analyse.

	disc spr	TALK spr affect	TALK spr argun	TALK spr know	TALK spr peers
disc spr		26 - 0,07	4 - 0,02	14 - 0,04	7 - 0,02
Q spr app compare	1 - 0,01	17 - 0,05	7 - 0,05	15 - 0,05	9 - 0,03
Q spr app explain	2 - 0,02	6 - 0,02	7 - 0,05	21 - 0,08	16 - 0,06
Q spr app interpret	4 - 0,03	9 - 0,03	9 - 0,07	17 - 0,06	15 - 0,06
Q spr app relate	1 - 0,01	8 - 0,02	3 - 0,02	17 - 0,06	12 - 0,05
Q spr app use model	3 - 0,02	10 - 0,03	9 - 0,07	18 - 0,07	11 - 0,04
Q spr know describe	3 - 0,02	10 - 0,03	6 - 0,04	10 - 0,04	11 - 0,04
Q spr know provide examp	1 - 0,01	8 - 0,02	7 - 0,05	26 - 0,10	30 - 0,13
Q spr know recall	6 - 0,06	8 - 0,03	7 - 0,06	37 - 0,16	15 - 0,06
Q spr reas analyse	5 - 0,05	15 - 0,05	18 - 0,16	27 - 0,11	17 - 0,07
Q spr reas design investiga	n/a	6 - 0,02	n/a	2 - 0,01	1 - 0,00
Q spr reas draw concl	1 - 0,01	8 - 0,03	8 - 0,07	5 - 0,02	2 - 0,01
Q spr reas evaluate	n/a	2 - 0,01	n/a	1 - 0,00	n/a
Q spr reas formulate	2 - 0,02	1 - 0,00	8 - 0,07	17 - 0,07	9 - 0,04
Q spr reas generalize	n/a	3 - 0,01	1 - 0,01	6 - 0,02	1 - 0,00
Q spr reas synthesize	2 - 0,02	3 - 0,01	1 - 0,01	n/a	2 - 0,01

FIGURE 1. Overlap of dimensions of interdisciplinary group talk with question types, screen shot from 14.7.2017.

In the current coding and C-coefficient analysis, the connection between Affective dimension and disciplines has diluted with its combining with the Peer dimension. Provide examples shows up in the current c-coefficients, but now, Interpret information seems to co-occur with the Peer dimension more often than Analyse.

The Reasoning dimension shows similar c-coefficients for the above-listed question types, but in addition, even higher coefficients for Recall, Compare, and Relate question types.

The Knowledge dimension shows high c-coefficients (0.10 or more) for Recall and Explain question types again, but Use models and Formulate questions do not stand out in the analysis today.

What should I make of this comparison?

It is good to note that the clear connections with high c-coefficients are still there in today's data. The discrepancies could stem from the intercoder discussions and clarifications in dimensions of interdisciplinary group talk coding (such as being more careful about labelling something with the code): this is evident from the numbers e.g. in Reasoning overlapping with Analyze questions dropping from 18 to 13. In the coding comparison phase, Reasoning category was restricted in how any meandering explanations would not end up as Reasoning, but that it would be related to explaining and elaborating on a previous statement.

Another reason may be that in 2017, I may have included one more document than I ended up having in the end (this is not clear from the files where possible candidates for analysis were discussed, and the documentation within Atlas.TI was lost).

Based on this comparison I would not assign much meaning to small differences in the C-coefficients – 0.07 is not very different from 0.05 as there were several items that changed within these ranges. But having a C-coefficient of 0.10 or more for an overlap seems to be a lasting connection and can be treated as reliable under these coding circumstances. The only exception to this pattern is the drop in Reasoning / Analyse co-occurrence numbers and c-coefficient, which seems to be due to making stricter guidelines in the coding manual, but this is not an absolute explanation to the drop.

APPENDIX 4: GLOSSARY OF TRANSCRIPT SYMBOLS

Glossary of transcript symbols

Here only markings used in this thesis are shown. This text is adapted and shortened from Jefferson, G. 2004. Glossary of transcript symbols with an introduction. Pragmatics and Beyond New Series 125, 13-34.

[	A left bracket indicates the point of overlap onset.
=	Equal signs indicate no break or gap. A pair of equal signs, one at the end of one line and one at the beginning of a next, indicate no break between the two lines.
(0.0)	Numbers in parentheses indicate elapsed time by tenths of seconds
(.)	A dot in parentheses indicates a brief interval (± a tenth of a second) within or between utterances.
____	Underscoring indicates some form of stress, via pitch and/or amplitude. A short underscore indicates lighter stress than does a long underscore.
::	Colons indicate prolongation of the immediately prior sound. The longer the colon row, the longer the prolongation.
↑↓	Arrows indicate shifts into especially high or low pitch.
?	Punctuation markers are used to indicate ‘the usual’ intonation. These symbols usually occur at appropriate syntactical points. Sometimes, at a point where a punctuation marker would be appropriate, there isn’t one. The absence of an ‘utterance-final’ punctuation marker indicates some sort of ‘indeterminate’ contour.
WORD	Upper case indicates especially loud sounds relative to the surrounding talk.
°word°	Degree signs bracketing an utterance or utterance-part indicates that the sounds are softer than the surrounding talk.
<	A post-positioned left carat indicates that while a word is fully completed, it seems to stop suddenly.
> <	Right/left carats bracketing an utterance or utterance-part indicate that the bracketed material is speeded up, compared to the surrounding talk.
< >	Left/right carats bracketing an utterance or utterance-part indicate that the bracketed material is slowed down, compared to the surrounding talk.
.hh	A dot-prefixed row of ‘h’s indicates an inbreath. Without the dot, the ‘h’s indicate an outbreath.

wohhrd	A row of 'h's within a word indicates breathiness.
(h)	Parenthesized 'h' indicates plosiveness. This can be associated with laughter, crying, breathlessness, etc.
£word£	The pound-sterling sign indicates a certain quality of voice which conveys 'suppressed laughter.
( )	Empty parentheses indicate that the transcriber was unable to get what was said. The length of the parenthesized space reflects the length of the ungotten talk.
(word)	Parenthesized words and speaker designations are especially dubious.
(( ))	Doubled parentheses contain transcriber's descriptions.