UNIVERSITY OF COPENHAGEN

PhD thesis

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Praxeologies and Institutional Interactions in the Advanced Science Teacher Education

This thesis has been submitted to the PhD School of the Faculty of Science, University of Copenhagen

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Submitted: 2016/01/31

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Title / Subtitle:	Praxeologies and Institutional Interactions in the Advanced Science Teacher Education
Title in Danish	Praxeologier og institutionelt sammenspil i ASTE
Description:	This thesis reports on research in the context of the Advanced Science Teacher Education (ASTE). Special focus is given to interaction between the teaching disciplines of science and mathematics, as well as interaction between universities, university colleges and lower secondary schools participating in ASTE. The Anthropological Theory of the Didactic is employed to investigate and analyse practice and theory related to curriculum development, course implementation and practicum learning.
Supervisor:	Carl Winsløw
Submitted:	January 31st, 2016

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Acknowledgements

First of all I would like to thank Carl Winsløw for being there in the shuttlebus after CERME 5, which in subtle ways can be said to be the beginning of my journey towards the completion of this thesis. As my supervisor, Carl has been instrumental to my induction in the realm of the anthropological theory of the didactic. He is a brilliant theorist and has been unwavering in his support and constructive in his expectations.

Then my thanks to all involved in the ASTE education, who are too numerous to credit properly, but here goes: Karen Vesterager, Ole Goldbech, Jens Aarby, Henrik Levinsen, Helen Nyboe, Eva Rønn, Nina Troelsgaard Jensen, Charlotte Krogh Skott, Iben Merete Højsgaard, Ditte Marie Pagaard, Martin Hermansen, Nanna Benjaminsen, Sanne Snell Nielsen, Nicolai Munksby, Rikke Juul Hormbøl, Theis Hoppe, Kristian Foss, Camilla Helsteen Østergaard and many more at the involved schools, university colleges and universities!
And a special thanks to all the ASTE pre-service teachers for letting me ask and record a thousand questions! My project would not have been possible without your kind cooperation.

Great thanks must be extended to all the people at IND. I have to mention Britta Eyrich Jessen, Miku Yoshida, Dynana Iswanti, Sofie Kobayashi, Ane von der Fehr and Jacob Bahn who perhaps had to endure must of my sudden questions.

I would also like to acknowledge the Metropolitan University College and Lundbeck Foundation for economical support as spirit and enthusiasm only gets you so far.

Finally I thank Cecilie and particularly my beloved family Caroline, Jacob and Anne for going with me to Japan and helping me always to keep the right perspective in life.

Abstract

The present thesis consists of six papers that address three important aspects in mathematics and science teacher education: 'Integrating two or more teaching disciplines', 'learning from practice' and 'interaction between institutions'. These aspects are studied in combination as they have unfolded in the context of developing and implementing a Danish education programme called the Advanced Science Teacher Education (ASTE), that aim to educate lower secondary school teachers, who among other things are to excel at interdisciplinarity.

The essence of integrated teaching is elusive and existing research have mainly attempted to pin down its nature by attempting to categorise and compare different forms of integration. This study takes another approach by using the Anthropological Theory of the Didactic to trace the comprehensive web of influences, which are at the core of actual disciplinary interaction. This approach makes it possible to explain why and how certain notions are able to bridge the disciplinary divides. The papers in the thesis deal with curriculum development, and with concrete ideas as to how teacher educators could carry out teaching conductive to learning disciplines in conjunction. In particular the inquiry process of Study and Research Paths (SRP) is experimented as a promising design to bring about disciplinary interaction. SRP is internationally a very recent design, entirely new to Danish teacher education, and the thesis add to the knowledge of its merits.

'Learning from practice' is mainly dealt with in the setting of lesson study, a format which is gaining importance in the Danish educational community. Through lesson study in ASTE it is shown how a number of usual didactic tasks in mathematics teaching at Danish lower secondary schools is practiced and theorized. This is realised by analysing the reflection session inherent to lesson study, where the particular institutional setup in ASTE provided an unmatched venue for the elaboration of didactic knowledge. The gain in didactic knowledge is both particular and general, and to the benefit of pre-service teachers, mentoring teachers, teacher educators and university researchers.

The study of interacting institutions in ASTE is inseparable from the other aspects, as focus is on the processes which shape the nature of integrated curriculum and courses. Preferences held at each institution, and presumptions held of other institutions, played a significant but often unrecognized role in curriculum development and inspired actual elements of teaching. To handle the complexity of disciplinary and institutional interaction, the thesis proposes an extension to the model of didactic co-determination, and describes a possible reference model which fit interdisciplinary issues.

Abstract in Danish

Denne afhandling består af seks artikler, der behandler tre vigtige aspekter i matematik og naturvidenskabelig læreruddannelse: 'Integration af to eller flere fag', 'læring fra praksis' og 'samspil mellem institutioner'. Disse aspekter undersøges i kombination, som de har udfoldet i forbindelse med udvikling og gennemførelse af et dansk uddannelsesprogram kaldet "Advanced Science Teacher Education" (ASTE). Uddannelsen har til formål at uddanne lærere til grundskolens ældste klasser og udmærker sig blandt andet ved at være opbygget med sigte på tværfaglighed.

Essensen af tværfaglig undervisning er svær at få hold på og eksisterende forskning har primært forsøgt at indfange dens karakter ved at kategorisere og sammenligne forskellige former for tværfaglighed. I denne afhandling tages en anden tilgang, som ved hjælp af den Antropologiske Teori for Didaktik, søger at kortlægge det omfattende net af påvirkninger, som udgør kernen i fagligt sammenspil. Denne tilgang gør det muligt detaljeret at forklare hvorfor og hvordan visse tematikker, er i stand til at bygge bro over faggrænser. Artiklerne i afhandlingen beskæftiger sig med udvikling af studieordninger, og med konkrete ideer til hvordan undervisere kan gennemføre undervisning som fører til læring i sammenspil mellem fag. Specielt undersøgelsesprocessen i såkaldte Studie og Forskningsforløb (SFF), der er et lovende design til at skabe fagsammenspil, er blevet testet. SFF er internationalt et nyere didaktisk design, der er helt nyt for dansk læreruddannelse, og som afhandlingen således bidrager til viden om.

'Læring fra praksis' er hovedsageligt behandlet gennem analyse af lektionsstudier, et format som breder sig i det danske uddannelsessystem. Gennem lektionsstudier i ASTE vises det, hvordan en række af udbredte didaktiske handlinger i matematikundervisningen praktiseres og teoretiseres. Dette opnås ved at analysere den refleksion, som er et centralt element i lektionsstudier, og hvor det særlige institutionelle setup i ASTE udgør et uovertruffet mødested for udveksling og udvikling af didaktisk viden. Den opnåede didaktiske viden er både speciel og generel og til gavn for lærerstuderende, praktiklærere, læreruddannere og universitetsforskere.

Studiet af institutionelt sammenspil i ASTE er uadskilleligt fra de andre aspekter, da fokus er på de processer som former karakteren af tværfaglige studieordninger og kurser. Præferencer hos hver institution, og formodninger om andre institutioners præferencer, spillede en væsentlig, omend ikke fuldt erkendt, rolle i udviklingen af studieordninger og inspirerede til konkrete elementer i undervisningen. For at håndtere kompleksiteten af interaktioner mellem fag og institutioner foreslås i afhandlingen en udvidelse af modellen for didaktisk co-determination, ligesom der beskrives en mulig referencemodel for tværfaglige tematikker.

List of abbreviations and word usage

The intention with this list is to support the readers and provide easy reference to frequently used abbreviations and words, which usage differ from journal to journal. Hopefully it will be mostly superfluous.

ASTE	Advanced Science Teacher Education
College professor	(Same as *Educator*, *UC professor*, *Teacher educator*)
Core ASTE courses	The four interdisciplinary courses of the reformulated ASTE
Discipline	The general, ideal notion of a discipline. The academic notion of a discipline
Educator	(Same as *UC professor, Teacher educator, College professor*) the person who in various ways provide or conducts the elements of teacher education. Institutionally affiliated with a UC
Guiding teacher	(Same as *Mentor teacher*) the LSS teacher with special obligation to help and provide guidance for the preservice teachers when in practicum.
DSE	Department of Science Education (in Danish: Institut for Naturfagenes Didaktik) Department at the University of Copenhagen involved in the ASTE project.
In-service teacher	A licensed teacher working in LSS
Institution	Smaller or larger aggregation of people sharing praxeologies. Some such institutions are so permanent and impervious to the flux of constituent people that they are considered societal institutions. Schools are an example of such institutions.
interdisciplinary	In this thesis, the same as *integrated*, *multidisciplinary* etc.
Layer	Same as *institutional layer* or *societal institutional layer*; signifies an organizational and managerial part of the educational system. E.g. universities are an institutional layer in the educational system. An ecology defined at the institution level of co-determination.
LSS	Lower Secondary School
Mentor teacher	(Same as *Guiding teacher*) the LSS teacher with special obligation to help and provide guidance for the preservice teachers when in practicum.
Prospective teacher	(Same as *Pre-service teacher* and *Student teacher*.) The persons attending teacher education. Word preferred by the Journal of Mathematics Teacher Education.
Pupil	The persons attending education in LSS. *Pupils* are taught by LSS teachers.
Steering Committee	The group of people responsible for developing and running ASTE.
Student	General term for the learners in a formal educational system. This term has

	been avoided whenever possible to avoid doubts about on which layer a person is a student.
Student teacher	Same as *Pre-service teacher* and *Prospective teacher*. This term has been avoided whenever possible to avoid confusion with “students” in general
Subject	Name for a discipline as it manifests at LSS
Supporting teacher	Principally the same as *Guiding teacher* or *Mentor teacher*, but without the formal obligation. Often “just” the teacher of a subject in the LSS class where the preservice teacher performs practicum.
Teacher	The general unspecified term. Particulars implicit from the context.
Teacher educator	(Same as *Educator, UC professor, College professor*)
Teaching Discipline	Name for a discipline as it manifests at UC
UC	University College. The societal institutions offering teacher education in Denmark. For historical reasons separate from Universities.
UC professor	(Same as *Educator, Teacher educator, College professor*)
UCC	University College Capitol
UCM	Metropolitan University College

Introduction

This thesis comprises the main elements of my academic work during the last four years. It contains six papers, three which have been accepted for publication in international peer-reviewed journals, two which have been published in peer-reviewed proceedings of international conferences and one in a reviewed booklet published by the University of Copenhagen. They are presented in an order reflecting the overall flow of objectives in my research project, incidentally the first and last paper is also temporally the first and last I wrote. During the research period I have worked and collaborated to produce four other publications which are spin-off products of a sort (Nyboe & Rasmussen, 2015; K. Rasmussen, 2012; K. Rasmussen & Goldbech, 2013; K. Rasmussen & Isoda, 2014). These have not been included in this thesis because they only indirectly relate to the research objectives. However they add to the context in which the research project is situated, and might thus enlighten the interested reader. The data material collected for this thesis comprises many documents and particularly audio recordings of meetings and interviews. A number of the documents have been made publicly available and can thus be found through the references. Other data are referred directly to the unpublished sources, but are available for review upon request.

In the following section, I present the background and context for the reported research project. I will then situate the project in relation to existing research regarding interdisciplinary science teacher education followed by a theoretical overview and a statement of the research objectives. This will pave the way for an outline of how the papers each deal more specifically with the objectives and finally, I will present my conclusions and offer some perspectives.

The Context of the Advanced Science Teacher Education

My research project is as indicated by the title closely associated with the Advanced Science Teacher Education (ASTE) whose characteristics and background will be presented here in quite some detail as it provides the context for my research. A pragmatic reason for supplying the full context here is that such context is usually not possible to include in the papers, where space limitations dictate a very short and concise description narrowly associated with the objective of the paper in question. Consequently there is a risk of losing “the big picture”.

ASTE at a glance

The international (Western) background for ASTE is to be found in the perceived general challenge of engaging the coming generations in mathematics and science (Osborne & Dillon, 2008), a challenge which at times has been touted as a reason for a downright shortage of mathematics and science teachers (Ingersoll & Perda, 2009). This challenge is mirrored in Denmark and is still unresolved although initiatives are continually launched to combat the tendency (Dohn & Højgaard, 2014; Nielsen, 2014). ASTE can be seen as such an initiative. Initiated in the beginning of 2011, it was going to be an experimental educational programme running alongside the ordinary national teacher education. A consortium was formed between the Department of Science Education (DSE) at the University of Copenhagen; The Danish School of Education at Aarhus University; the Metropolitan University College (UCM) and University College Capital (UCC). The consortium was, and is still represented by the Steering Committee, which run the daily project affairs of ASTE. The Steering Committee consists of one project leader (from UCC) and one representative/educator from each of the consortium partners. Funding was secured from the Lundbeck Foundation and ministerial approval was received in January 2012. A series of meetings and workshops were held at the behest of the Steering Committee to formulate the ASTE curriculum and everything was set to receive the first prospective teachers in September 2012. However this was not going to be the case (K. Rasmussen & Goldbech, 2013) Without implying a causal relationship, a reform bill was passed in July 2012 by the Folketing (the Danish Parliament), altering ordinary Danish teacher education and slightly to few applied to join ASTE. As a consequence ASTE had to be reformulated and inauguration had to be postponed to September 2013.

Before going further into the original and the realised ASTE and I will shortly outline which more specific problems the consortium highlighted as reasons to develop the experimental education (Goldbech, Vesterager, Aarby, Winsløw, & Benjaminsen, 2011). First was the general concern over Danish pupil’s average score in PISA science language skill tests, which was attributed to unsatisfactory teaching competency among science teachers. Secondly, collaboration between teachers of different science subjects in school was considered to be rare, although prescribed by lower secondary school (LSS) curriculum. Thirdly, teaching was not believed to be overwhelmingly informed by research or systematic reflection upon teaching practice. Fourth, the division of science teaching being carried out in three separate teaching disciplines (biology, physics/chemistry, geography) (and entirely apart from mathematics) made it difficult to promote an understanding of natural science as a whole. These four concerns should all be dealt with by improving teacher education, and the consortium proposed that ASTE could at least partially tackle the challenges by carrying out teacher education with an *interdisciplinary* approach to the science disciplines and mathematics, *cooperation* with universities and novel forms of *relations* with LSS through practicum.

The original ASTE intended to have intimate control of all elements of the experimental education, but after the setback, the high ambitions had to be relaxed. The resulting ASTE lost its experimental status and became an optional choice in the newly reformed ordinary teacher education: A specialisation with a core of four interdisciplinary courses, special events and lesson study as a bridge between coursework and practicum. An aim for excellence and synergy was also retained by structuring and remodelling the program so the prospective teachers would get authorisation to teach all four involved teaching disciplines where the ordinary education would only provide authorization for three. The reformulated ASTE was a success in terms of recruitment. The ASTE specialisation attracted enough prospective teachers to run at both participating university colleges (UCs) from September 2013, and a second "batch" of prospective teachers was started up in September 2014. (See also Table 5) At the time of writing the thesis mantle, the first batch is taking the last two of the core interdisciplinary courses, and still has three more semesters to go before they are ready to begin their professional career.

The original ASTE

The intention with the original ASTE setup was to develop and run an entirely new teacher education as an experiment alongside the existing ordinary teacher education. The elements of the ASTE programme were developed and aligned in several ways to cater for the education of superior teachers of the science and mathematics subjects. The nature of these elements and alignments will be elaborated in this paragraph.

The curriculum for the program's pedagogical and social courses was "toned" to support science and mathematics teaching disciplines. For instance the course from the ordinary teacher education, "Christianity, Enlightenment and Citizenship" (CEC), was added a dimension of Innovation (to become CEIC), and many passages in its curriculum text expresses well how the toning was intended:

> The aim is further to create a connection between the 'bildung' task of LSS and the science subjects, in an endeavour to foster appreciation of the scientific culture in LSS.
> ...
>
> A main task will be to face the question of being human, local citizen and world citizen in a globalized world with e.g. environmental and climatic problems as a common responsibility, and handling this in collaboration between the disciplines of science.
>
> Examples of this could be:
>
> - Working with ethical issues based on classic ethics which enables the pre-service teachers to evaluate contemporary ethical animal- and environmental dilemmas.

- Working with cultural and religious issues, focusing on the relation between belief and knowledge, as well as different cultural perspectives regarding the relations between man and nature.

- Working with the notion of democracy focusing on LSS as a place for democratic 'bildung' and development of socially relevant action competence, subsuming e.g. how mathematics contributes to acknowledgement of quantitative argumentation and reasoning.

(Goldbech, Vesterager, & Aarby, 2012b, p. 21)

The notion of '*Bildung'* is central to Danish educational thought. (Avery & Wihlborg, 2013; Olesen, 2009, 2011) And ASTE particularly wanted to foster a scientific and mathematical kind of Bildung, which was believed to be less well represented in LSS and ordinary teacher education, where teachers and pre-service teachers with a more classic arts and humanities outlook predominate. The CEIC course itself did not survive the reformulation, but the intention to tone and align social and pedagogical courses remained implicitly. (See next section.)

The original ASTE curriculum for the practicum was specially designed to link the pre-service teachers' coursework with the work at the practicum schools and in particular to accommodate lesson studies:

> ”The practicum comprises different elements with both practical and theoretical perspectives: planning, organizing, implementation, analysis and evaluation of teaching in open lessons and lesson studies, which are a special feature of ASTE practicum.” (Goldbech, Vesterager, & Aarby, 2012a)

For each group of pre-service teachers, the practicum was to take place at the same school. This would make it possible to follow the progression of the LSS pupils, and foster a close working relationship with the LSS teachers. Ideally the LSS teachers and teacher educators could align the coursework to the practicalities of the school reality. The intention was to initiate networks across the LSSs and UCs, especially the participation in lesson studies was hoped to foster a new spirit of collaboration centered on the learning of science and mathematics.

Last but most importantly, the curriculum for the teaching discipline courses of the ordinary teacher education was entirely restructured and integrated. Ordinary mathematics and science teacher education courses at the time were large courses of 36 ECTS (European Credit Transfer System) each. For instance to become a licensed LSS teacher of mathematics, geography and biology, the pre-service teachers were to pass four courses with these names: Mathematics Common, Mathematics Specialty, Geography and Biology, totalling 144 ECTS. Besides these large courses, the remaining ECTS up to 240 were given to social and pedagogical courses as well as a bachelor project. The original ASTE deconstructed the large courses and reassembled them into 10 discipline specific courses (or modules as they were called) together with 6 *interdisciplinary* courses. The compositions of the interdisciplinary ones are of special interest to this thesis, and their details will be elaborated in the following.

The interdisciplinary courses, each roughly with 10 ECTS weight, combined the teaching disciplines two by two under the names presented in table 1:

Original ASTE interdisciplinary course name	**Disciplinary combination**
1) The origin and development of life and the Earth	Biology and Physics/Chemistry
2) Energy and Climate	Physics/Chemistry and Geography
3) Agriculture and foodstuffs	Biology and Geography
4) Geographic Information Systems (GIS), data analysis and modelling in geography	Geography and Mathematics
5a) Biotechnology, models and data evaluation in industrial production OR 5b) Ecology, genetics as well as data analysis and modelling in Biology	Mathematics and Biology
6) Mathematical models in physics and chemistry	Physics/Chemistry and mathematics

Table 1: The interdisciplinary courses in the original ASTE. Note that two curricula were produced for the mathematics and biology combination (5a and 5b); which to use were never decided. (Goldbech et al., 2012b, pp. 47-59)

Each interdisciplinary course curriculum was developed during a series of seminars and workshops managed by the Steering Committee. At these meetings people from the three institutional *layers* took part: LSS, UC and the Universities. Likewise the disciplines or teaching disciplines were represented, each partaking discipline represented by educators from the UC layer, while at times only one of the disciplines had an university layer representation. The LSS representation was not as strongly linked to disciplines as was the case for the two other layers. The LSS representatives usually were proficient in both involved teaching disciplines, and several had already a little experience of teaching the science disciplines in an interdisciplinary fashion.

The course “Geographic Information Systems (GIS), data analysis and modelling in geography” is the focal point of the paper ‘*Didactic Codetermination in the creation of an integrated Math and Science Teacher education: The Case of mathematics and geography*’ which is the first paper included in this thesis. The course “Energy and Climate” provides the context for the second paper in the thesis: ‘*A layered model of didactic codetermination in science teacher education - Institutional conditions and constraints when planning multidisciplinary teaching of energy topics*’

The reformulated ASTE

The reform of Danish teacher education during the latter half of 2012 (Forligskredsen, 2012) resulted in the so called LU13 education act (Uddannelses-og-Forskningsministeriet, 2015), which replaced the LU07 educational act (Undervisningsministeriet, 2011). As the original, and in fact not realized, ASTE education was planned as an experiment relative to LU07; the ASTE consortium had to (re)-apply the Ministry of Education for permission to run it in the new "age" of LU13. This was denied as the ministry wanted a swift phase out of the ongoing LU07 teacher education. If the consortium wanted to continue with ASTE, they had to reformulate so it would fit into the ordinary LU13 education. The Steering Committee undertook this reformulation together with the educators from UCs who had participated in the original ASTE development. As a consequence the influence of the LSS and University layer on the exact wording of the reformulated ASTE curriculum became more limited. Two salient features of LU13 made it possible to reformulate ASTE without abandoning to many of the central ideas. Firstly the LU13 education was modularised, meaning it was to consist of a larger number of 10 ECTS courses, which the pre-service teachers to a higher degree would be able to choose freely. This was in contrast to the previous LU07 where the comparatively larger courses were mandatory once the direction of study was decided. This fitted well with the course structure intended in the original ASTE. The second salient feature was the option for each UC to develop locally the curriculum for a number of the 10 ECTS courses, thereby creating particular profiles, or specialisations, for the learning services offered at each UC. This was again in contrast to LU07 where all course curricula were decided nationally for all UC, which then in principle provided the same education. The choice for ASTE was obvious as the consortium in effect already had a whole catalogue of locally developed curricula: ASTE became an optional specialisation within LU13, which prospective teachers could choose at UCM and UCC. The core of the ASTE specialisation consists of four interdisciplinary courses with the following names and discipline combinations (See Table 2):

Reformulated ASTE interdisciplinary course name	Disciplinary combination
Sustainability – energy and foodstuffs	Geography, Biology, Physics/Chemistry
Health – risk or chance?	Biology, Mathematics
Energy and Climate	Geography, Physics/Chemistry
Nature's game of dice	Mathematics, Physics/Chemistry

Table 2: The interdisciplinary courses in the reformulated ASTE. Notice that the course "Energy and Climate" carries the same name as in the original ASTE, the only course curriculum which did not change substantially. (UCM and UCC LU13 Curriculum)

The course “Sustainability – energy and foodstuffs” is addressed in the third paper *‘The emergence and institutional co-determination of sustainability as a teaching topic in interdisciplinary science teacher education’* while “Health- risk or chance?” plays a central role in the fifth and sixth paper: *Didactic transposition of mathematics and biology into a course for pre-service teachers: A case study of 'Health - risk or Chance?’* and *‘The direction and autonomy of interdisciplinary study and research paths in teacher education’*

The reformulated ASTE kept the aspiration to reap synergistic benefits from the interdisciplinary setup, granting teacher licence for the four involved teaching disciplines if the pre-service teacher takes all four core ASTE courses. (As well as nine mono-disciplinary courses, six courses on general pedagogy, three practicum periods and a bachelor project period, all from the ordinary LU13 curriculum. (See Table 3 and 4 for the actual structure)) ASTE therefore moved on, and was advertised, as a “talent” program, where the pre-service teachers were subjected to the acceleration requirement of honouring the learning goals of four teaching disciplines in the same amount of time as allocated ordinarily to three.

Semester	Course names (each “box” nominally 10 ECTS)		
1	Math1: Mathematical learning, numbers and algebra	LG1: Bildung in the multifaceted school	LG3: The teacher profession in the globalized society
2	Math2: Geometry and Teaching of Mathematics	LG2: The teacher’s organisation of teaching.	Practicum
3	Bio1: Living organisms and ecological relations - pupils investigative and experimental work	Geo1: Geography - A world of change.	LG4: The disciplinary, social and personal learning and development of pupils
4	Phys/Chem1: The world of physics and chemistry	ASTE1: Health - risk or chance?	ASTE2: Sustainability - foodstuffs and energy
5	Practicum	ASTE3: Energy and climate	ASTE4: Nature’s game of dice
6	Math4: Mathematical tools and pupils with special needs	Bio2: Evolution, genetics and biotechnology – from everyday understanding to scientific understanding	LG5: Inclusion, special needs and teaching of bilingual pupils
7	Phys/Chem2: Development of scientific reasoning	LG6: The professional teacher	Geo2: Geography - the world around us
8	Practicum	Bachelor project	

Table 3: Structure of ASTE at UCM. LG1-6 are pedagogical and social courses intended to provide fundamental skills and knowledge of the teaching profession, not associated with any teaching discipline in particular.

Semester	Course name (each “box” nominally 10 ECTS)		
1	Math1: Mathematical learning, numbers and calculation processes	CEC: Christianity, Enlightenment and Citizenship (Bildung in the multifaceted school)	INTRO: To become and be a teacher – bachelor project intro
2	Math2: Geometry and Teaching of Mathematics	CEC: Christianity, Enlightenment and Citizenship (Bildung in the multifaceted school)	Geo1: Geography - A world of change.
3	Math4: Applied mathematics and pupils with special needs	Practicum	PG1: General teaching competence
4	Phys/Chem1: Pupil learning of the universe – from atom to cosmos	ASTE1: Health - risk or chance?	ASTE2: Sustainability - foodstuffs and energy
5	PG2: Pupil learning and development	ASTE3: Energy and climate	ASTE4: Nature’s game of dice
6	Bio1: Living organisms and ecological relations - pupils investigative and experimental work	PL3: Special needs pedagogics	Practicum
7	Phys/Chem2: Pupil learning of energy, technology and innovation	PG4: Teaching of bi-lingual pupils	Bio2: Evolution, genetics and biotechnology – from everyday understanding to scientific understanding
8	Practicum	Bachelor project	Geo2: Geography - the world around us

Table 4: Structure of ASTE at UCC. CEC, Intro and PL1-4 are pedagogical and social courses intended to provide fundamental skills and knowledge of the teaching profession, not associated with any teaching discipline in particular

Course	First Batch (autumn 2013)		Second Batch (autumn 2014)	
	UCM	UCC	UCM	UCC
Math1: Mathematical learning, numbers and calculation processes	22	24	31	16
Math2: Geometry and Teaching of Mathematics	22	23	29	18
Math4: Applied mathematics and pupils with special needs	15	22	NA	14
ASTE1: Health - risk or chance?	17	21	17	14
ASTE2: Sustainability - foodstuffs and energy	17	24	17	14
ASTE3: Energy and climate	15	17	NA	NA
ASTE4: Nature’s game of dice	15	17	NA	NA

Table 5: The number of pre-service teachers taking ASTE courses at each university college. The table shows the mathematics courses and the core interdisciplinary courses. Monodisciplinary ASTE science courses in corresponding semesters had an equal number of participants. All Pre-service teachers attending an ASTE designated course were given the “ASTE-treatment” regardless of their overall course of study. (Statement as of January 2016)

The reformulated ASTE would, as in the original, like to educate teachers who might serve as role models for a scientific philosophy of life. The proverb 'beacons of science' was frequently used to signify the hope of ASTE candidates spearheading a greater interest and appreciation of the scientific worldview in schools and teacher education. The Steering Committee wanted to cultivate an "ASTE-spirit" or "ASTE-identity" and have throughout the project arranged and sponsored bi-annual events for all participating ASTE pre-service teachers from both UCs. This has typically materialized as visits to science centers, open lessons or international guest lectures, frequently arranged with the university layer.

To nurture the ASTE-spirit within the program, the pre-service teachers intending to take the full ASTE package (the four core courses) have been grouped together at the earliest possible time. E.g. the ASTE candidates would attend the ordinary mathematics courses together during the first semesters, and they would embark on their long term association with the selected practicum schools (LSS). This arrangement made it possible to introduce and carry out lesson studies early on, and not just as part of the core courses. Educators in charge of the pedagogical and social courses for the ASTE "teams" made efforts to incorporate lesson study and make a "toning" towards the scientific teaching disciplines, but it never became as formalized as intended in the original ASTE. The pre-service teachers permanent association with the same LSS over the years proved untenable for many reasons, among which were cooperation difficulties, LSS schools getting other priorities, and ASTE students' wishes to explore wider the palette of different kinds of LSS. The Steering Committee however continued offering in-service courses to cooperating teachers from the ASTE LSS. Even attendance at study lessons held at LSS was sponsored, but practical and organizational obstacles made it difficult to get substantial participation. For instance the LSS teachers themselves had to find substitutes to conduct their own classes while they were away to witness a study lesson. The element of lesson study is the fulcrum of the fourth paper in this thesis: *'Lesson study in pre-service mathematics teacher education: Didactic and paradidactic technology in the post lesson reflection'*

The original ASTE intention of seeking cooperation with the university layer was also kept in the reformulated ASTE, and appears as such in all but the first paper. This cooperation has up till this time seen quite some difficulties, but also some success particularly in relation to the lesson studies.

Situating the research project

The present research project investigates certain aspects of ASTE, originally outlined by the Steering Committee, which handles the overall running of the education. The research connected to ASTE should focus on examining interdisciplinary practice and knowledge developed in the programme as well as on analysing the collaboration between the involved institutions (Goldbech et al., 2011). At the outset there was an intention to look equally much at the planning phase as the implementation phase and what this meant for the prospective teachers. However as ASTE had to be reformulated Medio 2013, this research project had to change too. By necessity focus had to be more on the planning phase; and the teacher educators' role in fostering interdisciplinarity and collaboration came more to the fore.

The present research project is situated within research on the preparation of teachers, a field that is complex and according to some reports lack the unified coherence and consensus known by other more mature research areas (Cochran-Smith & Zeichner, 2010). However a number of positions in this field of research have been identified which I will elaborate and situate the present project in relation to.

This project is delimited by the fact that it relates to educational settings where only the disciplines of mathematics and science are concerned. However several of the positions mentioned in the following have wider generality. A first way to position the study is to relate to the methodological research tradition which it follows. Borko, Liston, and Whitcomb (2007) refer to four genres of empirical research on teacher education: "Effects of Teacher Education" Research; Interpretative Research; Practitioner Research; and Design Research. Effect Studies try to link teacher education with student learning through a "cause and effect"-rationale, relying heavily on statistics and the hope of establishing correlations. The present thesis does not subscribe to that tradition. Rather it is firmly rooted in Interpretative Research which seeks to identify, analyse and interpret specific phenomenon. The aim is, among others, to improve practice and program design as well as to develop theory. In the Interpretative Research genre: "Data analysis is a recursive process that begins during data collection; themes and patterns are developed inductively from the data and deductively from the conceptual framework" (Borko et al., 2007, p. 5). The employed conceptual framework of the Anthropological Theory of Didactics (ATD) (Bosch & Gascón, 2014) offers theoretical guidance in analysis, while allowing for methodological freedom in the use of data sources. (See also next section.) The choice of ATD as theoretical framework influences, as all theoretical lenses do, what can inductively be found in the data available. It is a dialectic process. ATD focuses on the epistemological and institutional aspects of didactic phenomena, while regarding other aspects as less central. For instance individual beliefs are only "interesting" in as much as they can be said to be commonly held by parts of the institutional setup. Coming back to the desire of Interpretative Research to improve upon practice, this thesis also has an element of Design Research (with a tiny element of Practioner Research). According to Cobb, Confrey, Lehrer, and Schauble (2003) Design Research seeks to develop theory about learning and the means to support learning. This is usually done by performing an intervention that is prospective and reflective in relation to the theoretical design. The process is iterative and has the potential for rapid pay-off, in the sense that the theoretical products directly address practioners problems.

Research traditions aside, this thesis can be positioned "content wise" relative to research on teacher education in general, on which an impressive array of literature have been published over the years (See e.g. Brown & Cooney, 1982; Cochran-Smith, Feiman-Nemser, McIntyre, & Demers, 2008; Darling-Hammond, 2006; Sikula, 1996; Tisher & Wideen, 1990). Some of the literature deals specifically with teacher education inside the disciplines of mathematics and science. In particular the 15th ICMI-study on "The Professional Education and Development of Teachers of Mathematics" (Even & Ball, 2008) and the "Handbook of Research on Science Education" (Lederman & Abell, 2015) are useful in framing central trends in research on mathematics and science teacher education. Attempting the impossible by grossly oversimplifying the knowledge contained in the aforementioned literature, I venture five strands of mathematics and science teacher education research, which of cause are interconnected: Ontology & Epistemology, Psychological & Social Analysis, Society & Curriculum, Practicum Studies, and Professional Development. The *Ontological and Epistemological* strand is research about what constitutes knowledge for teachers, how it came to be defined as such and how is it possible to perceive and realise such knowledge. Lee Shulman's work on different kinds of teacher knowledge (Shulman, 1986) is one classic example, another being Yves Chevallards notion of didactic transposition (Chevallard, 1985) which explains how scholarly knowledge is changed and turned into teachable knowledge. To this strand I claim the present thesis contributes at least in some small way, particularly through the epistemological analysis inherent in the use of ATD. The *Psychological and Social Analysis* strand cover studies of issues such as affect, attitudes, beliefs, identity, motivation and gender. These matters are normally referred back to the individual person, his or her feelings and interactions with other individuals. This thesis does not concern itself much with this strand, only inasmuch as the matter can be ascribed to whole institutions in the ATD sense. *Society and Curriculum* cover studies of teacher education programs: How they are constituted? What does the curriculum encompass? What is the nature of course work? Which societal institutions educate teachers? In particular what role does the teaching disciplines play in the program? How do disciplines and institutions interact? This strand is substantively dealt with in this thesis. The fourth strand on *Practicum Studies* signifies research related to prospective teachers' practice, experimentation or investigation in school classrooms or other arenas where their professional work eventually is to be carried out (e.g. visiting museums etc.). Researching the nature of guidance from mentoring teachers and teacher educators is part of this strand, which obviously can have close links to the preceding strand, depending on the scrutinized program setup and the closeness of interaction between coursework and practicum. In this thesis particular emphasis is on *lesson study* as a format for investigating and reflecting upon practicum. The fifth strand, *professional development*, deals with research on in-service teacher education, the life-long development and continued improvement of teaching ability ideally taken on by all professionals. This thesis does touch upon this, in the sense that the teacher educators in ASTE develop their interdisciplinary and didactic praxeologies by being part of the project (see next section for the definition of praxeologies). Also mentoring teachers and university academics who participate in the lesson studies can be said to partake in professional development.

Theoretical framework

In this section I give a coherent overview of the Anthropological Theory of the Didactic, whose individual elements have been employed in the papers. The theoretical notions of ATD will be explained and illustrated with examples from the research project which for various reasons did not find its way into the papers selected for this thesis. For the sake of clarity, the exemplification mainly stem from analysis of the same ASTE-course.

An exposition of ATD can start in several ways where the realisation of *didactic transposition* is often put forward as the place to start, as it is the historical starting point (Bosch & Gascón, 2006; Chevallard, 1985). However I choose to begin with the notion of praxeologies, which is the central tool to model various types of knowledge and practice in ATD (Chevallard, 1999). All human enterprise is proposed as consisting of two interrelated components: that of *praxis* (doing, practice) and that of *logos* (thinking, reasoning). In the following I first deal with praxis and from this move on to the logos.

The praxis part is often called the *practice block* and includes itself two subparts: *types of tasks* (usually denoted by a capital T) and a *technique* to handle the task type (usually denoted by τ). Types of tasks invariably define a minimal praxeology. Types of tasks can be broken down to individual tasks, and also further into more and more rudimentary tasks, but this is usually not meaningful, as the aim is to provide an adequate description of the task type, not to dissect it. (For instance a task to solve a mathematical equation is not usefully described by subtasks like lifting the pencil, finding paper to write on etc.!)

A type of tasks faced by the pre-service teachers in the ASTE course *"Health – risk or chance?"* were this: T: Investigation of linear relationships. This task type was embedded in the context of measuring blood pressure and weight of each participant and the measurements were entered into a spreadsheet. Therefore the particular task types were T_1: Is there a linear relation between weight and blood pressure? T_2: Explain your findings in the given situation.

In the case of T_1 the technique ($\tau_{1)}$ used, was the activation of linear regression functions in the spreadsheet (see figure 1). τ_1 can potentially resolve all tasks like T_1.

Vægt (i kg)	Blodtryk/sys	Blodtryk/Dia
55,1	119	75
57,3	109	70
58,5	103	59
61,8	110	70
63,3	137	83
72,8	127	77
78	140	73
79,1	114	73
79,9	128	69
81,5	130	69
100,2	162	95

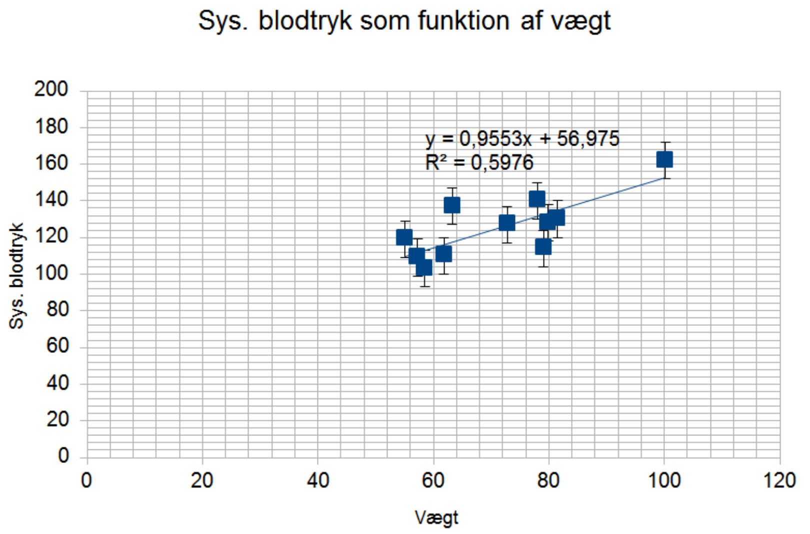


Figure 1: Extract from ASTE pre-service teacher's investigation of relation between weight and blood pressure.

In the case of T_2 the associated techniques branched into mathematics and biology. The technique ($\tau_{2,math}$) which falls within the mathematics discipline entailed looking at the coefficient of determination (R^2) and judging whether it was sufficiently close to one, suggesting a statistically significant linear relation. As this was not the case, the pre-service teachers argued that they might have an insufficient number of measurements or simply poorly performed measurements. The technique ($\tau_{2,bio}$) which drew on biology involved comparing male and female participants, as well as comparison to heavier and lighter animals such as elephants and dogs. Thinking of giraffes led to explanations showing doubts about whether to expect a linear relation on the basis of weight alone. Finally a biomechanical (or physiological) type of technique was ventured ($\tau_{2,biomek}$), reasoning from simple definitions of blood pressure, physical seize of blood vessels and volume of blood to be pumped. The three techniques for T_2 intermingled and can thus be interpreted as an example of an interdisciplinary praxeology.

The type of tasks and technique pairs showcased in the example are quite different in their explicit demand for logos. The logos of a praxeology is often called the *theory block* and consists, like praxis, of two subparts: A *technology* (denoted by θ) to explain or give reasons for the technique and a *theory* (denoted by Θ) to order, generalise, link or collect technologies into coherent aggregations of logos. Especially T_2 explicitly begs the pre-service teachers to expose the logos, indeed it would be difficult to have a technique for t_2, if the technology part of the theory block was sparsely developed. On the other hand T_1 could in principle be handled with the technique (τ_1) and a rudimentary technology (θ_1). Theory blocks are never empty; there is always logos behind praxis. It may be simple, limited or even misconstrued, but it is there.

Of this "4T-model" (T, τ, θ, Θ) of knowledge, the first T is the one most readily accessed, and it is increasingly difficult to get at up to Θ, which is the most obscure, and often the least consciously realised, even if it is usually interpreted in relation to the realm of scholarly institutionalised theories. The theory block of praxeologies is generally of interest to teachers and researchers alike. In fact the type of tasks T_2 from the example is of a generic kind often ventured by teachers to get information about the learners' theory block. The generic quality of task types like T_2 will in most cases force the person facing the task to focus on certain aspects of the situation in which the task is situated. A technique has to be chosen to which the pre-service teacher is able to give reasons, i.e. the technology part of the praxeology has to be relatively well developed and consciously accessible. Otherwise the task gives the learner the opportunity to become conscious of, or to develop, technology. Theory (Θ) can in principle, like technology, be accessed or inferred from discourse, even though this is not (yet) explored much in the existing literature.

Knowledge and practice modelled as praxeologies are institutionally situated. It matters if the praxeology "lives" at a university college, a research university, or a pharmaceutical company. In fact we there have basically different praxeologies, though they may superficially deal with the same content, e.g. genetic research which also appears in the course "Health – risk or chance?" mentioned above. Different techniques for the same task can be preferred at each institution, the reasons given for the techniques can be different etc. (Castela & Elguero, 2013). An epistemological (and often historical) analysis of praxeologies will ideally reveal the differences and hint at their origin. In order to conduct such an analysis a reference model has to be elaborated which detach the analyst (the researcher) from the institutions under scrutiny (se also figure 2). Such a reference model is ideally a bunch of praxeologies, whose numbers quickly becomes impractical to handle explicitly unless the praxeological field is within relatively limited and well-ordered disciplines like mathematics (e.g. like in Barbe, Bosch, Espinoza, & Gascon, 2005). Therefore reference models are often elaborated in other, yet operationalizable ways (see e.g. Durand-Guerrier, Winsløw, & Yoshida, 2010). This is also what I have done in the second paper (*'A layered model…'*) and the third paper (*'The Emergence and Institutional Co-determination of Sustainability…'*) of this thesis.

Of particular interest to ATD is to study how knowledge moves between institutions, especially when it moves into and within the institutions of educational systems. In this process knowledge changes to become something which is teachable. This is the didactic transposition (Chevallard, 1989) often depicted generally with just four principal steps (see figure 2):

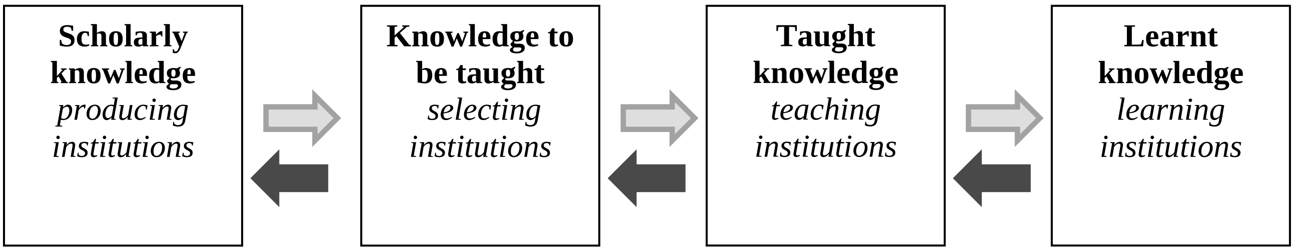


Figure 2: Overall steps of a didactic transposition. The bold text gives a name for the "quality" of knowledge, while the text in italics alludes to the institutional situated-ness. An epistemological reference model provides a vantage point outside these institutions.

It is important here to note that institutions in ATD are very flexible entities. Institutions can be both societal institutions in the sense of Douglas (1986) and communities of practice in the sense of Wenger (1999). In the ASTE project, and quite generally, the knowledge producing institutions are often veiled by the past. Most knowledge which enters teaching was produced a long time ago, but when more recent knowledge was taken up in ASTE, it usually came from university-like research institutions. The knowledge selecting institution in ASTE was the Steering Committee and the working groups it established. Actual teaching institutions were individuals or team of educators from the university colleges, while the learning institutions were the groups of pre-service teachers.

While didactic transposition theory provides a *dynamical* description of the epistemology behind praxeologies, ATD also provides the framework for a *static* description: The scale of levels of didactic co-determination (Chevallard, 2002). A praxeology is said to reside in an *ecology* where those *levels* influence each other (see figure 3).

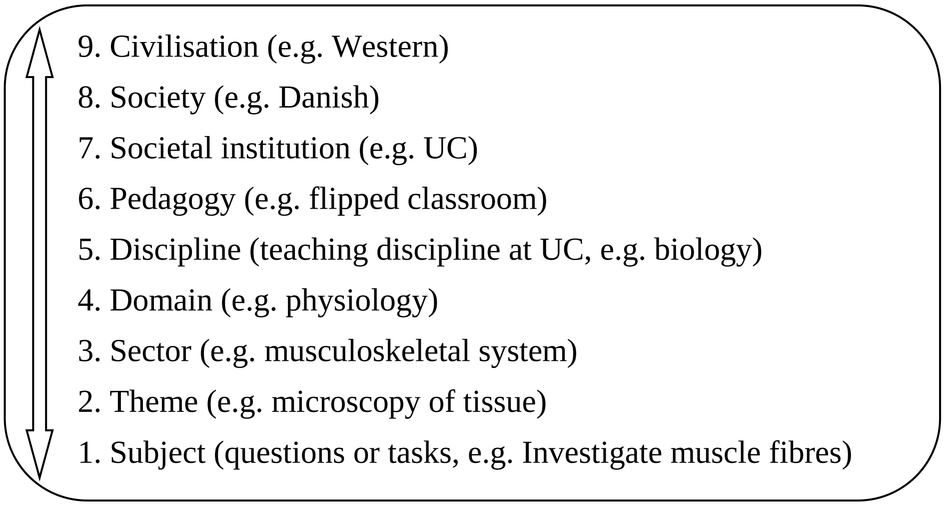


Figure 3: Levels of the scale of didactic co-determination. The vertical arrow indicates that all levels influence each other. The levels conditions and constrains the development of praxeologies. Particularly the lower levels (1-4) are relatable to the four parts of a praxeology

Ecologies can be defined at any level. In this thesis I do so at the discipline level (5) and the institution level (7), like in figure 3, where the examples are given from a disciplinary ecology of biology and an institutional ecology of UC. When emphasizing the institutional ecology I call the ecology for a *layer* of the education system. Each layer has its own set of levels, just as each discipline has its own set of levels (see in particular the second paper in the thesis: *'A layered model…'*)

Two "types" of praxeologies are of special interest. First the disciplinary praxeologies which express doing and knowing in direct relation to the discipline itself. And secondly the praxeologies of helping others acquire knowledge. The latter has been coined didactic praxeologies (Bosch & Gascón, 2002) and are of cause essential to teacher education. Didactic praxeologies are intimately related to the disciplinary ones and are heavily influenced by the didactic transposition process and the levels of co-determination. They are much harder to provide reference models for, as didactic research is comparatively younger as a field of study than the disciplines themselves. Didactic praxeologies unfold in teaching situations. Teaching situations often takes place in classrooms, a physical component of the *didactic infrastructure* (Chevallard, 2009; Winsløw, 2011b) which makes teacher work possible. But the teachers work is not limited to the teaching situations themselves, e.g. preparation and development requires support which ATD models as paradidactic infrastructure (Miyakawa & Winsløw, 2013) Paradidactic infrastructure shapes the work of the teacher outside the classroom. Lesson Study can be regarded as a paradidactic infrastructure aimed at improving didactic praxeologies. The lesson study setup in ASTE provided a window into the reasons behind didactic praxeologies, which is the focal point of the fourth paper:

'Lesson study in pre-service mathematics teacher education: Didactic and paradidactic technology in the post lesson reflection'

Finally two remarks are in order: Praxeologies are also called "organisations" in ATD, a term I have only used in the fifth paper, mainly because I seek to avoid confusion with other meanings of the word *organisation*. Another thing is that types of tasks, often taken as the defining starting point of praxeolgies, are not necessarily phrased as questions as might be surmised from the particular types of tasks in the above example of investigating linear relationships. A lot of human doing and knowing is not realised as a response to an explicit question, which is quite natural in many cases, e.g. the mundane task of tying shoelaces is often presented as a paradigmatic, albeit trivial, example. But in teaching situations one would surely expect most tasks to take the form of questions. This is not the case, according to Yves Chevallard much of education has been reduced to visiting *monumentalised* knowledge (Chevallard, 2006, 2012). We teach and learn *about* linear relationships, and we have forgotten the questions to which linear relationship is the answer. The questions contained in T_1 above are not questions pointing to the raison d'etre of linear relationships, and might therefore not be the best way to start scientific and mathematical inquiry. ATD offers a framework called *Study and Research Paths* (SRP), to escape the paradigm of 'visiting monuments', where T_1 can be clearly situated as a stepping stone on the path to answering a much larger question which provides the rationale of the praxeologies learners have to acquire. The nature of SRP is the central theme in the fifth and particularly the sixth and final paper: *'The direction and autonomy of interdisciplinary study and research paths in teacher education'*.

Research Objectives

The Ph.D.-project investigates three *aspects* of ASTE. These aspects all reflect the possibility of ASTE to improve three kinds of interaction:

A. Between the disciplines of science and mathematics within the teacher education.

B. Between course work and teaching practicum within the programme (specifically lesson study).

C. Between the institutions of higher education (university colleges and university) and the lower secondary schools.

The anthropological theory of the didactic allows me to study these quite different kinds of interaction *in connection to each other*, as all practice and theory is modelled as praxeologies which are completely dependent on, and determined by, their *ecology*.

In relation to aspect A the project objective is to perform selected cases of praxeological analysis: Either interdisciplinary praxeologies that occur in the planning or realization of ASTE, i.e. praxeologies based on task types which allow for two or more of the involved disciplines to be mobilized together; or didactic praxeologies which are realised by, or presented to, the preservice teachers, and which are co-determined by an interdisciplinary praxeology.

The project objective regarding aspect B is theoretically more general, namely that of orchestrating “learning from practice” which is, for the most part, constituted by work which are integral parts of courses at the UC, and during the practicum periods. The institutional part of the analysis becomes apparent here because the modalities of infrastructures like lesson study are instrumental to the ways in which prospective teachers develop their knowledge and practice from shared observation and shared reflections on the practice.

Finally in connection to aspect C, the objective is to position the institutional analysis in a wider perspective, as the disciplinary and didactic praxeologies involved in ASTE courses and practicum will be co-determined by the new constellation of co-operating institutions, for which, also significant constraints and perhaps even obstacles to communication and collaboration are likely to occur.

It is important to stress again that these objectives are not scrutinized independently of each other, and are to some degree all present in each of the papers presented below. However the following overview will outline which objectives each paper primarily deals with.

Overview of papers

This section explains how the research objectives are dealt with by each of the papers.

Didactic Codetermination in the creation of an integrated Math and Science Teacher education: The Case of mathematics and geography

This paper deals mainly with aspect A. It gives a review of literature pertaining to ‘interdisciplinarity’ (Jantsch, 1972) and similar labels for disciplinary interaction. The focus is deliberately on teacher education and investigates how elements from the teaching disciplines of mathematics and geography were envisioned to combine in one of the original ASTE courses. The interactions among the disciplines are modelled by juxtaposing two disciplinary ecologies. Through interviews with the educators about which types of tasks they had considered for the course, it was uncovered how the levels of one ecology influenced the other and vice versa. Particularly consideration of the lower levels of co-determination, which parallels more direct praxeological analysis, exposed the detailed interdisciplinary features. Furthermore, influences from "outside" the two disciplinary and UC situated ecologies were detected (dubbed as "second order influence"), and this later became the basis for a theoretical enlargement of the model of codetermination, which was used in the following paper.

A layered model of didactic codetermination in science teacher education - Institutional conditions and constraints when planning multidisciplinary teaching of energy topics

This paper deals primarily with aspect C (and A) and introduces the notion of institutional *layer* to investigate the complex genesis of interdisciplinary course curriculum with respect to both influence among different disciplinary ecologies as well as different institutional ecologies. It follows the steps in the didactic transposition process of another of the original interdisciplinary ASTE courses, where the involvement of two other societal institutions besides the UCs came to the fore. With this explicit institutional setup it was necessary to outline an epistemological reference model which could describe differences in the prevailing praxeologies regarding the teaching of energy topics as seen from "outside" the institutions. The enlarged model of co-determination, and the proposed reference model, made it possible to follow in details the formation of the course curriculum as it developed around the energy topic. It is seen how energy became the interdisciplinary focal point.

The emergence and institutional co-determination of sustainability as a teaching topic in interdisciplinary science teacher education

This paper capitalises on the theoretical developments in the preceding two papers. It deals again primarily with aspect C (and A), and utilises the enlarged model of co-determination and a structurally similar reference model. Here the focal point is 'sustainability' which like 'energy' emerges as a notion to which the science disciplines can all rally. How this rallying took place under the influence from levels of the disciplinary and institutional ecologies is captured by the enlarged model. The model provides answers to how, and in what ways, the differences in how each teaching discipline conceptualises sustainability continues to make sustainability a contested topic. Furthermore this paper not only deals with course planning, but also implementation, thereby taking in a larger part of the didactic transposition process.

Lesson study in prospective mathematics teacher education: Didactic and paradidactic technology in the post lesson reflection.

This paper deals primarily with aspect B, going deeply into didactic praxeologies as they are expounded in discussions where all three institutional layers in ASTE participated. Lesson Study has a well ordered paradidactic infrastructure with pre-didactic, didactic and post-didactic phases, where the last one constituted the perhaps most promising institutional interphase experimented by the ASTE-project. In the post-lesson reflection, the lesson study participants discussed the mathematic and didactic praxeologies observed in the research lesson. By doing so, post-didactic praxeologies intended to improve the aforementioned praxeologies was exhibited. The paper elaborates the technology of these post-didactic praxeologies, which some institutional layers display more than others. It is also shown how lesson study is debated as a new paradidactic infrastructure to orchestrate learning from practice, and (of cause) the particular didactic praxeologies of one exemplary lesson study case is presented.

Didactic transposition of mathematics and biology into a course for pre-service teachers: A case study of 'Health - risk or Chance?'

This paper sees a return to the process of didactic transposition. It deals primarily with aspect A and considers the "*meta"-nature* of didactic praxeologies for teacher education, which are somehow *twice removed* from the disciplinary praxeologies they are destined to develop. Teacher educators use their didactic and disciplinary praxeological equipment to help pre-service teachers develop didactic and disciplinary praxeological equipment which in turn helps pupils acquire disciplinary praxeologies. The paper has two distinct parts where the first is an analysis with fine-grained steps in the transposition process which brought forth the case course. The second part is an introduction to Study and Research Paths as a didactic infrastructure. More specifically as an inquiry process which could be ideal in interdisciplinary teaching contexts such as the core ASTE courses.

The direction and autonomy of interdisciplinary study and research paths in teacher education

This paper deals primarily with aspect A (and B). It falls in direct continuation of the previous paper as it covers the full implementation of the study and research path introduced there. The pre-service teachers themselves were to undertake an inquiry process, concerning the illness diabetes, which were exemplary for the didactic infrastructure of study and research paths. Moreover the presented SRP featured the test-run of two hitherto little explored theoretical constructs form ATD, which are intended as measures for the teacher to guide and direct the flow of the study process. The paths realised by the pre-service teachers are analysed in *tree diagrams* of investigated questions, providing information about the ability of the didactic setup to foster a self-sustained study process with interdisciplinary connections.

Conclusions and perspectives for further research

This section extracts conclusions from the research papers, which on their own are self-contained entities with specific research questions and sharpened conclusions. The aim here is to collate the overall findings linking them directly to the objectives, while subsequently pointing out the perspectives for further research along each of the three aspects.

Regarding aspect A, a great number of praxeological analyses have been performed. Either explicitly described in terms of the *4T-model* or more implicitly described through the models of didactic co-determination. It has been shown that interdisciplinary praxeologies were evident in the planning and envisioning of the original ASTE courses. Developing educators from the UCs were keen to think of types of tasks which provided the starting point from which the disciplinary interaction could play out. Such thinking shaped, and was shaped by, the levels of the disciplinary ecologies. This was evident in meetings and the developed course curricula. In many cases from both the original and the reformulated ASTE, the interdisciplinary cooperation could be tied to certain notions like flow, energy or sustainability, which appeared of value or interest to all the participating teaching disciplines. Using the models of co-determination it was possible to map the details of influences among the disciplines, providing a more comprehensive picture of interaction than is possible using the usual descriptive labels like ‘interdisciplinary’, ‘multidisciplinary’ etc.

It can further be concluded that SRPs as a didactic infrastructure contain didactic praxeologies helpful towards the development of interdisciplinary praxeologies. SRP was explored in the ASTE course ‘Health-risk or chance?’ where the nature of the involved didactic tasks were concretized. Two techniques (“selective picking” and “guiding questions”), which have been theoretically proposed to guide the inquiry processes, were considered and reasoned about. With the right timing, these techniques can be used to make the pre-service teachers go respectively ‘wide’ or ‘deep’ in their study process. Furthermore, the post-implementation analysis also revealed it was difficult for the pre-service teachers to cover both the disciplinary and didactic inquiries within the given timeframe.

The perspective of further research into aspect A is to do praxeological analysis of implemented courses which have been run several times, where initial teething troubles have been resolved. This will ideally make the analysis more straightforward, and might eventually lead to the identification of patterns of interaction which are most successful in integrating two or more teaching disciplines. Analysis of the experimented elements of SRPs pointed out preferable characteristics of the didactic techniques of “selective picking” and “guiding questions” as well as hinting at a lower limit to the duration of such an inquiry process. It would be most pertinent to include these findings in the next iteration of the course and redo the analysis of praxeologies developed by the pre-service teachers.

The research contained in the papers regarding aspect B is obviously most substantial regarding lesson study, but a number of other elements in the core ASTE courses fall within the realm of “learing from practice”. For example pre-service teachers themselves trying out usual (or unusual) practices of the profession, or interviewing pupils regarding selected areas of their knowledge. Indeed ASTE courses entailed enactment of didactic praxeologies intended to be exemplary for teacher practice, just as visits to external learning environments for pupils were frequently used and also in focus at the common ASTE events arranged by the Steering Committee.
Lesson study became the hallmark of ASTE in its cooperation with LSS. It was utilised during the practicum periods as well as during coursework, where lesson plans were developed with very specific foci and subsequently the research lesson was showcased at LSS. The lesson study work primarily presented in the thesis concerns a pilot study within the mathematics teaching discipline. Among several findings it was revealed how the paradidactic infrastructure of lesson study had to compete against existing ways in which to orchestrate ‘learning from practice’. This firmly documents the importance of a sustained effort with smaller consecutive introducing steps if lesson study is going to be a widely used format in Danish teacher education. In particular technologies (again in the ATD sense) were identified as conductive or the opposite to facilitate learning from reflection upon practice. Most significantly the reported lesson study showed the ability of the format to expose pertinent didactic praxeologies and thus enable reflection upon them in a forum where all three involved institutional layers could benefit from each other’s perspective. The elaborated didactic praxeologies took their starting point in a number of praxes very distinctive and commonly observed in the mathematical classroom: Conducting mathematics oriented whole class discussions, supporting pupils’ independent mathematical exploration and fostering their mathematical communication. Particularly reflection upon the last praxis provided a clear example where “taken for granted” institutional views were suddenly questioned, opening up for a

development of the corresponding logos, which would be highly unlikely if ASTE lesson study did not provide this “meeting place” for LSS, UC and University.

The perspective for further research of this aspect is obviously to scrutinize lesson studies conducted in relation to the core ASTE courses. This is essential to become knowledgeable of ‘learning from practice’ when more than one teaching discipline is involved. And there are sure to be particular conditions and constraints to the unfolding of interdisciplinary lesson studies as UC and LSS cooperation around practicum is ordinarily channelled through the teaching of single disciplines.

It would also be pertinent to conduct an action oriented research into the use of lesson study as a format to develop interdisciplinary teaching at UCs and LSSs and not only through the involvement of pre-service teachers. The potential of lesson study could be just as great in interdisciplinary settings as in monodisciplinary ones, but next to no research of this is to be found in literature.

Regarding aspect C it can be concluded that the institutional co-operation did in fact present a number of conditions and constraints which affected the ASTE-project. While this did not come as a surprise, what matters is the nature of the influence triggered by the participating institutions.

The pervasive intention of ASTE to involve all three institutional layers gave rise to expressed perceptions about disciplinary and didactic praxeologies at each layer. This appeared necessary in the endeavour to come up with ideas for cooperation. The actual truth-value of such perceptions cannot be established, and is in fact inconsequential. Each layer had commonly held views of its own and other layers, something which gave rise to misgivings about other layers’ apparent lack of knowledge about one’s own layer. This was not necessarily a bad thing as the cooperation provided fora to exchange information between layers, however frustrating it were at times. The UC layer in particular payed attention to curriculum for LSS and how teaching was perceived to take place there (i.e. perception of didactic praxeologies enacted in LSS). This definitely influenced curricula and actual teaching of the ASTE courses. While the attention to LSS is not novel to ASTE, it was here characteristically focused on the teaching of the identified interdisciplinary notions like ‘energy’ and ‘sustainability’.

Finding opportune ways to cooperate with the university layer challenged the educators in ASTE. However two influences could be ascertained: Seeking out research literature was observed to be a more frequent element of the pre-service teachers’ study practice. And educators’ inspiration for the developed curricula could be traced, albeit indirectly, to the university layer.

Another constraint affecting ASTE stems from having more than one discipline with its “own” educator involved in the same course: The teams of educators from participating disciplines planned together, but in most cases did not have resources or opportunity to teach together. In most cases it was hard for the educators to help pre-service teachers connect the teaching disciplines, when each educator did not know in detail what had happened in previous lessons. The organisational setup strongly conditioned what was practically attainable, and the reformulated ASTE had to run in an institutional reality where predominantly monodisciplinary courses were taught by a single educator representing just one discipline.

There are several research perspectives regarding this aspect which could be explored in the future: Foremost is analysis which takes either the LSS or the university layer into central focus. How was teacher education perceived by representatives of these layers in the ASTE project? What conditioned their involvement? Did ASTE, or more specifically lesson study, leave a (lasting) mark on the participating LSSs and universities, like it did on the UCs?

As ASTE pre-service teachers goes through the rest of their education, it will be interesting to explore the nature and quality of their bachelor projects as well as looking at their exam results. Are there significant traces of the institutional and interdisciplinary setup? When ASTE pre-service teachers graduate, it will be pertinent to study the ASTE teachers' first years of working in LSS, as this hold the important perspective of adding to our knowledge of the relations between teacher education and actual teaching within the profession.

Didactic Codetermination in the creation of an integrated Math and Science Teacher education: The Case of mathematics and geography

Abstract. This paper presents an application of the Anthropological Theory of the Didactic to describe and analyse the genesis of an integrated mathematics and science pre-service teacher education. Reporting from the pre-experimentation phase, it is shown how the levels in the scale of didactic codetermination enable us to understand more clearly how integration is envisaged. We examine more closely the case of a bi-disciplinary teaching-module wherein math plays one part together with geography, and we demonstrate how the scale can be used to explore the precise nature of the intended interaction between the two disciplines.

Introduction to the ambiguities of integrated education

At the turn of the century, Czerniak, Weber, Sandmann, and Ahern (1999) made a literature review of science and mathematics integration. They concluded that a lot of "testimonials" existed for the positive benefits of integration, but few empirical studies actually supported this notion that an integrated curriculum is better than a well-designed traditional curriculum. They also emphasised that the term "integrated" was shrouded in ambiguity, with no clear distinction between the diverse labelling of the many-named phenomenon: interdisciplinary, multidisciplinary, cross-disciplinary, trans-disciplinary, thematic or blended, just to mention a few. Ten years later, Stinson, Harkness, Meyer, and Stallworth (2009) reported a similar lack of common characterizations when asking teachers to identify given scenarios as integrated or not. They further concluded that:

> "Potential gains from integration (i.e., time savings, improving on student achievement, improving student interest or motivation) are predicated on a common understanding for what integration means. At the very least, curricula or initiatives designed to foster integration must develop operational definitions for integration before laying claims to an integrated approach or product" (p.159)

The problems with specific labels like "multidisciplinary" or "interdisciplinary" are at least twofold: First, as indicated above, we have no commonly acknowledged definitions: In Andresen and Lindenskov (2009) p. 213-214, multidisciplinary was used to signify a cooperation with clear delimitation of the individual disciplines, proposedly in contrast to interdisciplinary where borders *between disciplines are claimed to be more or less cancelled*. In the same paper, interdisciplinary is synonymous to cross-disciplinary, and trans-disciplinary is a radical form where no borders between disciplines are acknowledged. Completely opposite distinctions are found in Matthews, Adams, and Goos (2009), p.892, where interdisciplinary refers to curricula in which there is a mixture of science and mathematics although the *boundaries of the two disciplines remain visible*, and “integrated” is used to signify the lack thereof. A second, perhaps more profound problem is the principal inability of the labels to specify in any detail how the interaction between the disciplines is carried out, let alone what predicates the conditions of the interaction. For this reason too, we need a precise epistemological model of integrated mathematics and science education.

Theoretical framework and research questions

In this paper we chose to use the term “integrated” to signify *any* educational setting where two or more institutionally established disciplines are intended to work together in order to bring about learning. It is thus used as an overarching name encompassing all the other labels which are usually employed to signify more specific ways of conducting integrated education. The Anthropological Theory of the Didactic (ATD) describes what happens in educational situations as situated in an institutional ecology. Such an ecology is described by a hierarchy of levels, cf. figure 1.

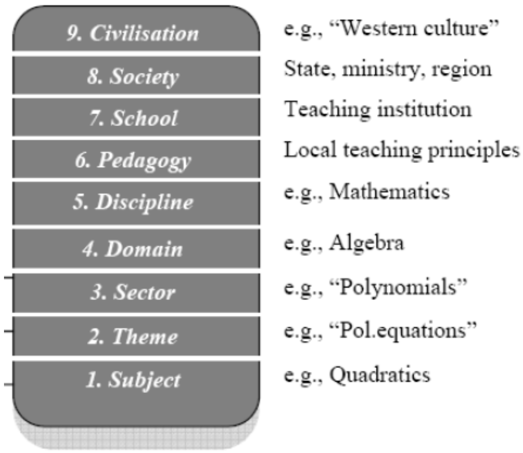


Figure 1: Mono-disciplinary ecology regarding quadratics. (Taken from Winsløw, 2011a, p. 133)

This means that the conditions on one level depend on influences from other levels of the ecology. This interdependency is articulated using a scale of levels of determination (see Artigue & Winsløw, 2010; or Chevallard, 2004 for more details). In integrated education we are considering at least two such ecologies where an explicit decision has been made to cooperate. We can then identify at which level the decision has been made, at which level the cooperation is meant to take place etc. At most times it will be understood that the cooperation is initially defined at the disciplinary level when considering integrated mathematics and science education, but note that our definition of “integrated” also encompasses cooperation initiated on other levels e.g. the math teacher and the science teacher could agree to use “cooperative learning” (Kagan) during their respective lessons in the same class, thereby situating the integration on the pedagogy level. Focusing on integration at the discipline level, we have the following framework for investigating the disciplinary cooperation, indicated in figure 2.

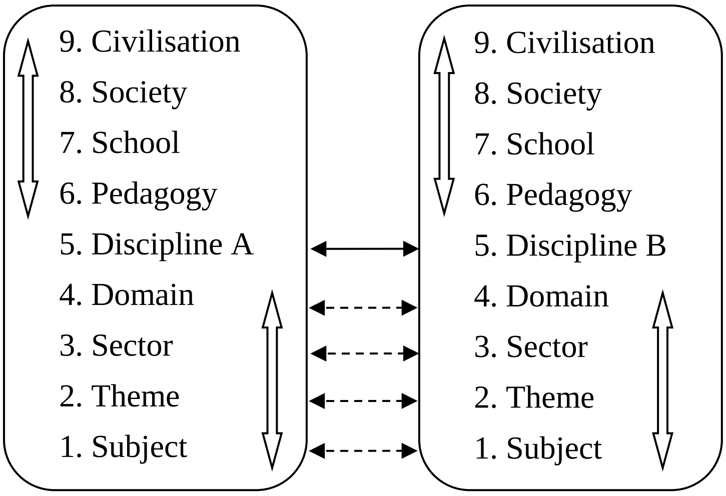


Figure 2: Levels of co-determination for bi-disciplinary ecology

Above the discipline level, the two ecologies are in principle the same, because we are considering the disciplinary interaction *at the same institution*. It is important to note that “mathematics” and “geography” appears as disciplines in closely related, institutional contexts (such as lower secondary schools, universities, and “university colleges”) and while these appearances are indeed different and bound to the institutions, they are also strongly linked. In this paper we will limit ourselves to look at disciplines inside one institutional context (university college) only. This means that influences from same-name disciplines in another institutional context, like universities, comes into our model at a higher level (mainly society). This we will call *second order influence*. It is now possible to model some of the central questions associated with the two integrated disciplines. The first type of questions concerns the “knowledge to be taught” (Bosch & Gascón, 2006):

> “What bodies of knowledge are chosen? How are they named? Why these ones and why with this kind of organizations? What are the reasons to these choices?” (p.56)

The answers to these are determined at the level of the discipline, and the levels above, as indicated by the leftmost vertical arrows.

The second type of questions concerns the levels below the disciplines, where the interaction is realised. These are usually more controlled by the teacher, but still constrained from above (Bosch & Gascón, 2006):

> "Why are mathematical contents divided in these or those particular blocks? Which are the criteria for this division and what kind of restrictions on the concrete activity of teachers and students does it cause?" (p.61)

While both types of questions are phrased the same way for mono-disciplinary education, they take on special meaning when more than one discipline is involved. Decisions taken from the perspective of one ecology have to be informed by the other. This is indicated on figure 2 by the horizontal arrows, where the solid one indicates the level at which the cooperation is formally defined, and the dotted ones signify the possibilities of interaction, whose existence and character may be further specified in a particular context, e.g. as part of the planning of an intended curriculum. This leads us to summarise the following research questions: What are the main features of the interplay between institutionalized ecologies in the planning of integrated math and science education? How can we study the "integratedness" in an inductive way, starting with actual and concrete plans for interaction, rather than with general rhetoric that tends to blur the detailed features? What conditions the planning and cooperation in integrated approaches?

Our Context and Methods

Teacher education in Denmark is institutionally placed at so called "university colleges", which are higher education institutions independent from research universities. A consortium between the University of Copenhagen, University College Copenhagen and the Metropolitan University College was formed to construct an experimental teacher education program (called ASTE, Advanced Science Teacher Education). The goal was to investigate, among other things, the synergistic effects of a multi-disciplinary science teacher education. The students are to become teachers of math and science in the lower secondary school, and the design of ASTE has been developed jointly by participating college and university professors. One of the main characteristics of the program is that large proportions of ordinary curricular items have been placed in bi-disciplinary teaching modules. In this paper we will apply the theoretical framework to study the development of the module named: "Geographical Information Systems, data analysis and modelling in geography", where parts of the math and geography contents are to be taught together. It should be noted that the geography discipline in Danish lower secondary school and at Danish teacher education colleges covers both physical and human geography, and the module we consider here also reflects that.

To shed light on the planning of this interplay we have conducted qualitative interviews with the five developers of this particular module; one math and geography college-professor from each university college (below referred to as CM_1, CM_2, CG_1 and CG_2) and one university-professor from the geography discipline (called UG) and with special interests in education. The institutional affiliations are rather complex in the ASTE-collaboration, but we will present them here because the institutional setting is of importance to our model: The two math college-professors are women, and although at the time of the interviews they represented two separate colleges, one of them had only recently changed from one to the other. The two geography college professors, male and female, come from another university-college than the two math professors. It should be noted that it is only the college professors who are expected to do the actual teaching, and the programme is implemented in the *physical* institutional setting of a branch of one of the participating university colleges, to which only one of the college professors (math) belong. The ASTE program comes with its own *formal* institutional settings that are written down in general sections of the curriculum, parts of which are tailored specifically, while others are adopted directly from the ordinary institutional framework.

The interviews were conducted in August 2012, beginning with a pilot interview of one geography college-professor. Informed thereby a scheme of questions were designed, and it was decided to ask the interviewees in advance to think of 1) a concrete activity to undertake in the module and 2) if possible, try to think in broad terms of an “entire” plan of action for the module. This aims to follow the inductive approach, starting with the levels below the discipline level. The interviews were semi-structured and lasted approx. 40 minutes each. They centered on two distinct parts: The design of the specific module as situated in the framework of ASTE and further thoughts on the realisation thereof. There was a focus on the individual respondent’s perceptions and experiences from the curriculum drafting work, seen in relation to their stance in the existing education system.

Data Handling and Results

All the interviews were recorded electronically and subsequently inventoried minute for minute. The quotations in the following subsections are translated and transcribed from oral Danish by the authors, and are indexed according to their temporal placement in the interviews

Determination of curricular items for bi-disciplinary integration.

Most of the curricular items chosen from each of the disciplines (see figure 3), From Geography:

- Knowledge, theories and problem from physical and human geography
- Skills at using geographical sources and methods
- IT as integrated part of the discipline in university college and lower secondary school
- Knowledge to further students geographic language and “bildung”
- Skills to utilize informal arenas of learning and employ investigative methods of inquiry

From Math:

- Geometry, specifically analytic, parametrizisations and trigonometry
- Using and evaluating appropriate representations
- Defining, structuring, mathematizing, interpreting and critique of mathematical models
- Skills at planning, organizing and evaluating teaching.

Figure 3: Curricular items chosen for the module: “GIS, data analysis and modelling in geography”

are recognizable to both mathematics and geography teachers, that is, they have suggestions about what an item from the other discipline could contribute to their own, but generally they do explicitly acknowledge their lack of expertise in the other discipline e.g.:

> My challenge is that I do not know much about the geography discipline in teacher education …so although I do understand the words, I have difficulties knowing what contents they represent, because I do not know much about geography as a discipline in teacher education. But on the other hand, it is also what makes such cooperation enormously exciting. It is exactly to become knowledgeable about the other disciplines. Are the problems they work with similar to those of math, and how is it about methods? This, I think, could be enormously exciting to get insightful about. (CM_1; 16:11-16:42)

This supports the notion that the intended integration, instigated at the discipline level, is indeed formal, but there is the desire to make it real by getting to know the other discipline through cooperation, and this is even seen as a separate advantage. It is also evident that curricular items, formulated along the lines of “the use of IT” are recognizable because they are determined at the school and pedagogy level, which are common to the two disciplines. Then there are some items, the determination of which, are situated exclusively at the level of the discipline: “Using and evaluating appropriate representations” and “skills at using geographical sources and methods” are intrinsic to the disciplines, but they pertain to similar disciplinary categories, such as the use of abstract symbols or graphics to represent data.

One could wonder why, or why only, the geometry domain is mentioned from the math discipline, and not e.g. statistics or functions, which could go well together with "data analysis". The interviewees agree that it is a practical and in a way arbitrary choice, because other domains could be made to work out just as well, but there is obviousness to the pairing of geometry and physical geography, which in our model can be seen as determined on the civilization level:

> "It is something about the measurement of the earth and maps, it all fits together very nicely, scales and similarity, it is nearly obvious!" (CM_2 20:20-20:28)

The etymology of geo-metry and geo-graphy alludes to the kinship between the two and historically, one may contend that the choice of "maps" and "geometry" are the primary domains involved in the interaction, and is indeed natural and reflects culturally rooted views of the two disciplines and the links between them.

Co-determination of concrete activities in the module.

In fact, when it comes to respondents' ideas for teaching, they are all connected to the notion of maps: The reference to different kinds of maps, the making of maps, maps as a tool for investigation, the historical development of maps. This is determined both at the discipline level, but also conditioned by the requirements of the institution in which the pre-service teachers are going to teach (schools; this second order influence appears at the society level in our model):

> "Mathematics sometimes requires practical examples to illustrate what math is, and that is what you can do when working with mapmaking, ...because the math related to that, is also the math you use in lower secondary school" (CG_1 18:47-19:13)

In figure 4 we have shown an example of how to model the interdependencies surrounding the creation of a physical map, as the subject of a teaching activity.

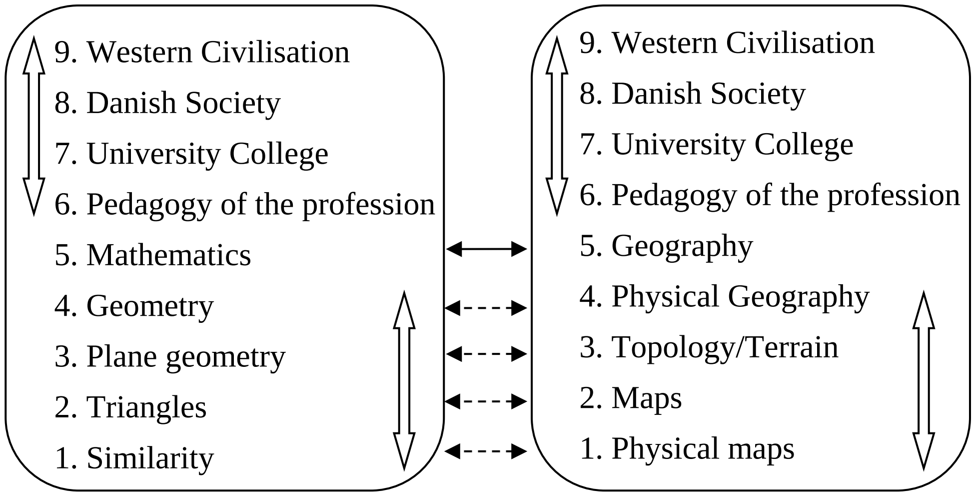


Figure 4 Example of bi-disciplinary ecology inferred from suggestions of interviewees

Using this model it is possible to identify possibilities and constraints that one discipline imposes on the other, to the enactment of such a teaching activity: At the domain-level, the choice of geometry, applied to the measurement of the earth, precipitates the restriction to physical geography. This in turn determines what should be the types of maps to work with: e.g. physical or topographic instead of other more culturally oriented maps such as political maps. Then distances could be the information you would like to convey using the map, and the choice of plane geometry might be taken to avoid the time-consuming complication of earth curvature and the different heights of the landscape being drawn on the map, especially if triangles are to be the mathematical theme. Triangles are used when making the measurements of the land considered as a plane surface, and then, by similarity, transferred to the map:

> "yes, that about surveying, at least triangulation and how maps has been made, and how maps look; I don't know how much surveying per se [they have in geography], when I think about surveying, it is more from a mathematical point of view, when we go out and construct figures out there" (CM_2 14:31-15:50]

> "It is clear that it would be tempting to measure on a sphere, meaning spherical geometry... but this [module] is not huge, so we have to be careful about how much we can achieve in the given time" (CM_2 24:42-24:57)

It may appear curious that the math teachers so willingly lend their discipline to the making of maps and surveying, but it is a common feature of Danish teacher education that applied math is considered of quite high value, which is also directly reflected in the curriculum description of the mathematics discipline at university colleges:

> "The history of the discipline, the discipline's function as a bearer of culture, and the application of the discipline, is an important part of its identity as a teaching discipline" Undervisningsministeriet (2011, appendix 2, section 3)

Looking at other suggestions to the possible contents of the module we find a lot of references to "problems of flooding and water flow" (CG_1 5:10, CM_1 19:20-19.37; 22:10, CM_2 15:20-16:00; CM_2 17:55-18:20). These are all strongly influenced by the society level:

> "It would be really nice if it [the context for teaching] could be some kind of real problem" (CM_1 22:21-22:28)

> "... but it [the problem of the teaching activity] is strictly a concern for society, it is all concerns for society" (CM_2 18:30-18:35).

Let us now select two of the concrete examples: 1) Investigating the impact of a new national law, proscribing that no land may be farmed that is closer to a stream than 5 meters. 2) Investigating the flow of water through a lake or stream. Both open up a host of possible teaching avenues, both for math and geography. In figure 5 and 6 we have put this into our model to describe how decisions at higher levels of the scale will interact to produce the possible integrated practice at the subject level. In both examples we recognize the aim to use Geographical Information Systems as a tool to do investigations, but GIS does not appear as an object of knowledge in itself. Therefore it is not mentioned explicitly in the model. It is used at the praxis levels (thematic and subject), and it is conditioned at the discipline level:

> "I think, it is because many who work with geographical information systems believe it is absolutely obvious that the whole world should know about it, because it is so incredibly smart and it appears in so many contexts" (CG_1 6:14-6:25)

It is worthwhile to notice that CG_1 expresses the desirability to have GIS included at the discipline level of math and geography, in the institutional ecology of the university college, whereas the reasons for the desire is said to come from parts of the society level, namely *those who work with GIS*. This is another example of a second order influence, which comes from an institutional context outside the university college (namely, from the same-name discipline in scientific institutions such as universities). Looking at the first avenue of teaching in figure 5 (example 1 above), we remark that it is directly determined on the society level as the idea originates from the consequences of a political decision.

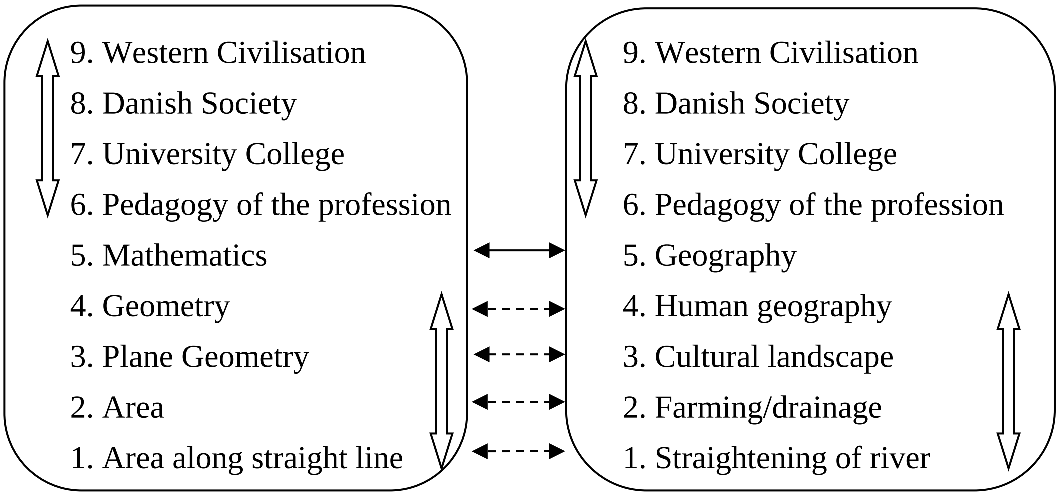


Figure 5 Example of bi-disciplinary ecology "Investigating impact of new law"

This clearly conditions the domain level to the geographical subfield of human geography, and the sector narrows it down to looking at culturally formed landscapes. Then what can be investigated mathematically is the area of farmland affected by the law, giving rise to the sector of plane geometry. One could hypothesize that the subsequent implications for the economy of the affected farmers could be mathematically considered, *but that would not be in strict accordance with the choice of geometry at the domain level*. As a consequence the theme and subject will, in regards to math, revolve around non-trivial calculations of area alongside curves, which could benefit from the aid of GIS. The geography part could draw on the area calculations and focus on issues of farming and the straightening of rivers (a classical subject of Danish human geography)

The second avenue of teaching (example 2, above) takes us into the "geometry of projections" sector of the chosen mathematical domain. (Figure 6)

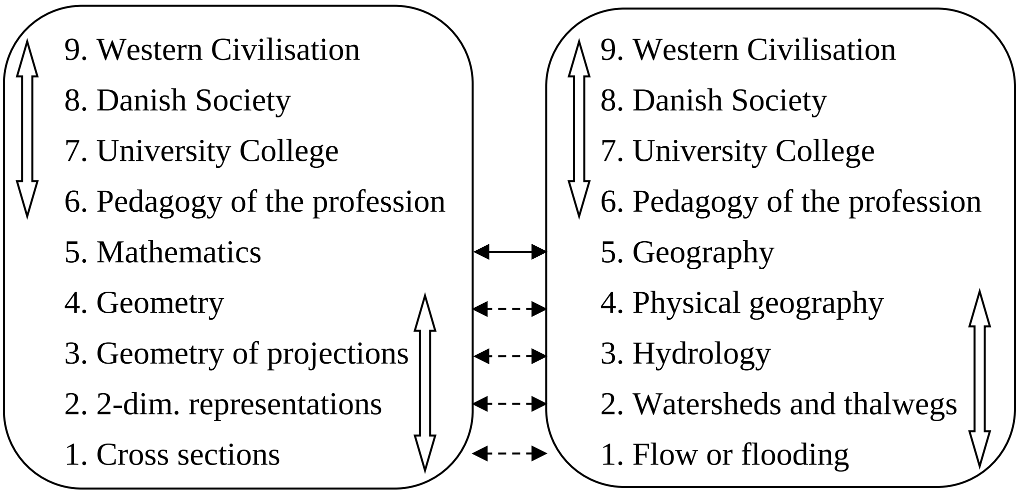


Figure 6 Example of bi-disciplinary ecology "Flow of water"

This is influenced by the choice of hydrology in the physical geographic domain, which has the study of moving water as an object. One theme could be thalwegs, in which two dimensional representations of river cross sections are extensively used. Also the cross section of the inlet and outlet of a lake, will determine the area of the lake surface. Horizontal cross sections of the lake landscape can be used to predict the extension of the lake for different flow rates:

> "We talked at some point about the flow through a lake, how the surface area, yeah, could be measured, but also how it changed in accordance with the flow in and out." (CM_1 19:13-19:31)

To construct the two dimensional representation, it is suggested that students physically go into the geotope and make the measurements using a mobile phone application, that can transfer data to a GIS system. Doing investigations in the field is an important part of geography, valued at the discipline level, and the processing of data to make the graphical representations, in this case, of river cross sections, is firmly rooted in the mathematical ecology at university colleges (school and discipline levels). The above quote may also allude to find some relationship or model of the changing lake surface area, expressed in terms of a function, as a pivot for the teaching activity. However, that would conflict with the choice of geometry at the domain level. This choice, if vigorously adhered to, seems indeed to impose rather strong restrictions on the lower levels:

> "You could easily get into functions here, and differential equations, if you look at the velocity with which the water runs from the lake. So that could be described in some dynamical systems, but we have nevertheless chosen that it [the module] should take another direction." [CM_1 29:15-29:39]

The two above analysed avenues of teaching both have common connection to the concept of "flow". This reminds us of what Wake (2011) calls a *bridging concept*, which "provide a driver to facilitate cross-disciplinary thinking” (p.1004). But we contend that the interaction among the different levels of didactic codetermination in the bi-disciplinary ecology provides a refined and more precise model of the idea reflected by the term “bridging concept”.

Conclusion and perspectives

The way two disciplines, as situated in the institutional ecology of teacher education at university colleges, interact, when trying to establish integrated education, are determined by factors residing at levels above the one immediately considered. The interaction crosses the disciplinary boundaries, meaning e.g. that the domain level of one discipline will influence the theme level of the other. The route of influence, as expressed in interviews with the developers of the integrated math and geography teaching module, can be modelled by the levels of determination, and *it goes by way of the vertically and horizontally indicated directions*. That is, we have seen no determinations that appear to go, for example, directly from the pedagogy level of the math disciplinary ecology to the theme level of the geography ecology. But the possibility of such level crossing codetermination in integrated education needs to be further investigated. This question, and the more general one of seeing borders between disciplines as a criterion of demarcation, is by no means a trivial one when we look at the long ongoing debate about the nature of integrated education. In the illustrations used to represent our model we have what appear to be clear borders between the participating disciplines. This is to recognize that our model *does* operate with disciplines as distinct bodies of knowledge and this also reflect evident conditions in the institutional context studied. Indeed, the curriculum construction in ASTE begins with the existing disciplines, which define relevant positions in the institutional context of the university college. In that fashion the disciplines come before “big questions” even in the early planning phases. The model is not to be taken normatively, and it does not say to which degrees borders do, or should be discernible, in order to represent “true” integration. It serves simply to organise our analysis of how integration of disciplines takes place, or is planned to take place. Finally it allows us to situate second order influences from same-name “scientific disciplines” and “secondary school disciplines” which co-determine the planning and cooperation in integrated approaches at the university colleges participating in this project. An extension of the model to study these influences further appears of great interest to understand more globally the interplay between participating institutions.

A layered model of didactic codetermination in science teacher education - Institutional conditions and constraints when planning multidisciplinary teaching of energy topics

Abstract. This paper investigates the institutional interplay when developing a multidisciplinary science teacher education. The teaching of energy topics is used as a case to illuminate how an expanded model of didactic codetermination can be used to analyse interactions among different disciplines and among different layers of institutions. The considered institutions are lower secondary schools, teacher colleges and universities, as they partake in the planning of an experimental teacher education program. Special emphasis is given to views held by institutions dedicated to pre-service teacher education, and influences between disciplines and the other institutions are described according to an elaborate reference model regarding "energy", which is also proposed in this study.

Introduction

Schools across the world currently organizes the "things" societies want its young members to learn into "compartments" called disciplines. This principle makes a lot of practical and historical sense, but it also creates significant challenges for education when the "things" do not fall directly within the established boundaries. This paper reports from the planning phase of an experimental teacher education, which seeks to turn these challenges into opportunities.

To appreciate the challenges one may refer to Chevallard (2012) who in his regular lecture at ICMI-12, speaks of the need to shift from a paradigm of monumentalized knowledge to a paradigm of questioning the world. In the present paradigm a teacher develops a lesson in a dialectic process between ideas, questions and desires on one hand, while doing a constant matching to fit a given discipline on the other. This is not bad per se, but it is somewhat artificial. There is a substantial risk that the questions become artificial. They become artificial questions that are defined and characterized by what will suitable for the acquisition of the monumentalized knowledge of the discipline. Disciplines can thus act as a severe constraint to the true inquiry into the questions that are the raison d'être for wanting to become knowledgeable. In the present world of compartmentalized knowledge, it becomes novel to allow searching for answers inside more than one discipline, and so ideas named "multidisciplinary", "interdisciplinary" or "integrated" education is born. In this paper I shall mainly use the term multidisciplinary, but otherwise not distinguish between the different terms. I shall investigate how contributions from different disciplines interact to ameliorate or loosen the constraints that the very same disciplines impose. I will expand upon the scale of didactic codetermination and take into account the fact that same-name disciplines live in different institutions that also shape them. This gives rise to an enlarged co-determination scale that "propagates in three dimensions", as will be explained in the theory section.

The main part of this paper is an analysis of the institutional interplay as it is envisaged in the *development* of an experimental Danish teacher education program, where the curriculum has been developed jointly by actors from three different institutional layers. Essential to the program is the aim to teach disciplinary knowledge in multidisciplinary settings, thereby focusing on common issues to take advantage of each disciplinary perspective and capitalize on the synergy between them. To ground the analysis I have chosen to look specifically at one of the bi-disciplinary modules of the program: "Energy and Climate", that seeks to combine physics (and chemistry) with geography. I will use the topic "energy" as fulcrum for investigations into the views valued at each institutional layer about the teaching related to this topic. The "energy-topic" is extensively studied in didactic literature, which enables me to build a detailed and concrete reference model of the views held by the institutional actors. The choice of "energy" is motivated by the fact that it possesses an inherent multidisciplinary character (Wijnsma, 2009) and furthermore it can be traced at all the layers of the Danish educational system under consideration in this investigation.

Theory and research question

The expanded model of co-determination

I propose to use the scale of didactic co-determination (Chevallard, 2004) as basis for a model of the complex determinations of multidisciplinary teacher education. I will consider an education multidisciplinary when two or more disciplines are brought together to be taught as a coherent whole. How the integration takes place depends on many issues inside the respective disciplinary ecologies. These ecologies live in institutional contexts, meaning that a discipline is not the same at e.g. primary schools, as it is at research universities (to take an extreme example). Varying institutions emphasizes different aspects of a discipline as important. (Bosch & Gascón, 2006) This happens to such an extent that one might regard chosen institutional preferences as being constitutive of unique disciplines in their own right. I will capture this essential feature and the integration between disciplines in an expanded version of the co-determination scale. (See figure 1)

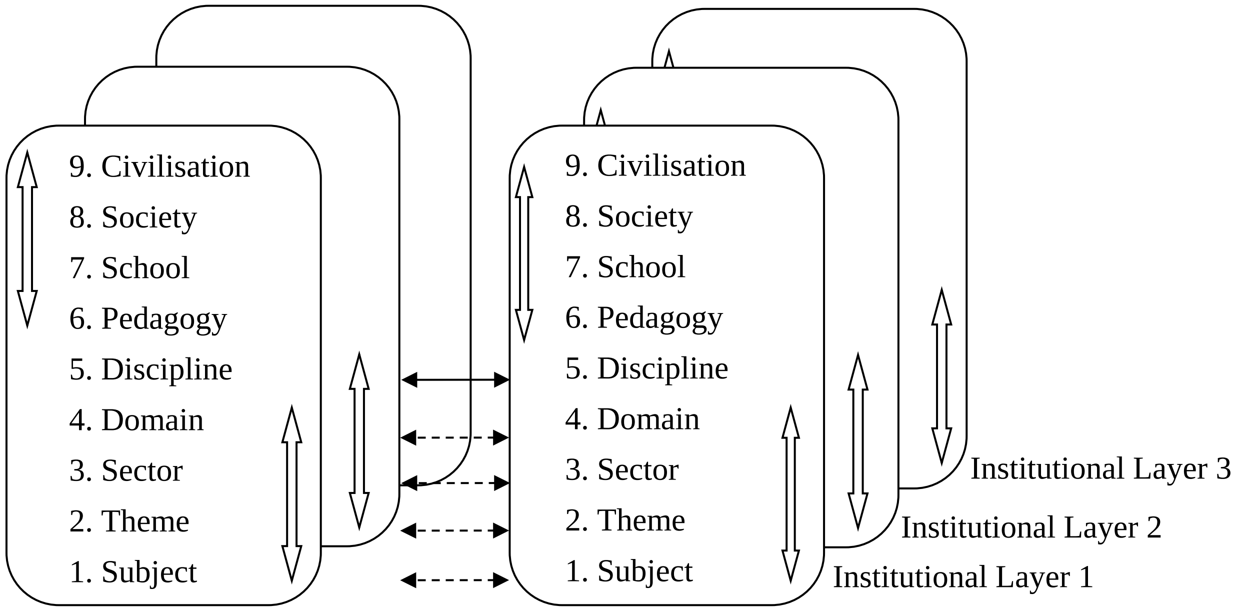


Figure 1: A layered model of co-determination for a bi-disciplinary ecology and three layers of institutional settings. (Note that while a discipline may carry the same name on each layer, the contents are not necessarily the same)

The usual levels of the scale are placed on the vertical axis of a three dimensional coordinate system, the extra disciplines are joined in along the horizontal axis and the extra institutional layers along an axis into the depth. This model allows for description and comparison of disciplinary ecologies across institutions, as well as across multiple disciplines. One can theoretically imagine influences that, figuratively, go diagonally in this model, e.g. from the level of School in one disciplinary ecology at layer 3 to the Theme level of another discipline at layer 1. In figure 1, I have taken the discipline level as the level that defines the ecologies, but of course any level could be used as focus to characterize the interaction one wants to emphasize.

While the above stated model can be used for any chosen number of institutions, I will only look at influences among three layers with pre-service teacher education as the central one. (See also the section on Context for this study, below) Pre-service teacher education belongs to an institutional layer "between" the one where a discipline is taught, (usually primary and secondary schools), and the one where the discipline is scientifically developed (usually universities). The disciplines may carry the *same name* on all three layers, but each layer has different priorities. This brings us to the main research question: *How to characterize the nature of integration between the disciplines in a teacher education institution, as it is influenced by the university layer and the lower secondary school layer.* The institutional layer of teacher education is in a field of tension (Elstad, 2010), where it is difficult to follow the paths of influences although everybody may agree that they exist. The tension is, among other things, seen in the form of continuous debate about how "academic" teacher education should be: How much of the time should teacher educators allocate to research and dissemination thereof? How much time to allocate to teach methods and practicalities of the teacher profession? There is a tendency to view theory and praxis as a dichotomy (Rodriguez, 1993), and this has been increasing over the past years, at least in the Danish context (Jensen, 2010). Therefore it is pertinent to employ the anthropological approach, which emphasizes the strong connection between theory and praxis of knowledge.

A reference epistemological model regarding "energy"

The investigation into the institutional interplay revolves around the *topic* "Energy" (as mentioned in the introduction). I will situate "energy" on the sector level of the model proposed above, while recognizing that it could be placed differently with regard to each scientific discipline or domain: The topic has meanings when expressed in ordinary, everyday language (Watts, 1983) as well as more specific meaning when used in the different sciences. Its widespread use gives it meaning as a concept in itself as well as part of procedures and in judgment of value (e.g. there is a value judgement in "energy from fossil fuels are bad") The literature is abundant with papers regarding research into the teaching of "energy" (M.A. Kurnaz & Calik, 2009 provides a review of the field). This abundance makes it possible to approach a reference model, and I will use Doménech et al. (2007) who give a detailed account of teaching issues regarding "energy" seen in its scientific, technological, societal and environmental aspects. Doménech et al. (2007) also review large parts of the pertinent educational research, and I will use that as a basis for establishing the reference model in ATD terms (Bosch & Gascón, 2006). The reference model is needed to explicitly state the way the researcher looks at a certain didactical problem and to detach *the study* from institutional determinations. In this paper I am interested in how the didactical challenges of teaching "energy" in a bi-disciplinary context can be used to highlight the institutional conditions and constraints. I will hypothesize that "energy-teaching" can be characterized by three *grand types of tasks* and their associated praxeological organisation, but for simplicity I shall only refer to them by the central character of the task. These task types are not mutually exclusive but, as we shall see below, they cover a continuum of questions about energy from the most fundamental and basic e.g. "What is it?" to the most diverse and complex e.g. "How does the flow of energy influence the Earths ecosystem"

The first grand type of task is related to the *conceptual* and *procedural* aspects of "energy" or what could more colloquially be deemed the "pure science"-part of energy-topics. Praxeologies in this category are concerned with the nature of "energy" and its epistemological status: Is it to be seen as a substance, a fluid, or a capacity to do work? Tasks of this type often involve calculations of, and use of, different “forms” of energy: kinetic and potential energy, chemical energy, thermal energy, electromagnetic energy, nuclear energy etc. Conservation of the quantity “energy” is central to tasks of this type:

> “There is a fact, or if you wish, a law, governing all natural phenomena that are known to date. There is no known exception to this law—it is exact so far as we know. The law is called the conservation of energy. It states that there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same.”(Feynman, Leighton, & Sands, 1963, p. 1, chapter 4)

An example praxeology connected to this first type of task can be taken from Van Huis and van den Berg (1999, pp. 147-148), where a simple electrical circuit consisting of a battery connected to a small lamp is considered. The task T is to identify the boundaries of the system, and give the energy-budget equation as derived from the first law of thermodynamics. The first law states that the difference between the sum of input and output energies of a system equals the change in internal energy. In the case where we take battery and lamp as the system, the lamp delivers heat (Q) and light ($U_{radiation}$) to its surroundings by decreasing the energy that is chemically stored in the battery. The equation becomes: $0 - (Q + U_{radiation}) = \Delta U_{chem}$ It is clear that this type of task is strongly co-defined by the technique τ: Define the system and assign suitable “forms” of energy to the right places of the equation. The technology θ involves the conservation principle and the discourse associated with energy-“forms”. The overarching theory Θ is thermodynamics. (Note that the use of heat and radiation as forms of energy is strongly contested (Doménech et al., 2007, p. 54), which I will elaborate in the next section).

The *second grand type of task* is related to the *transfer* and *harnessing* of energy. Central to these tasks are the transformation between different forms, or qualities, of energy. The exchanges uses mechanisms called “work”, “heat”, “radiation” etc., which are not themselves considered “forms of energy”. The tasks can be considered to belong to a “technology- or engineering”-part of the energy topic, with an emphasis on the utilization of differences in energy distribution. (Note here that the mentioned “technology” is not in the ATD sense) Entropy becomes an important construct in the theories associated with these tasks. Examples in the category ranges from qualitative considerations of energy exchange to quantitative calculations of combustion processes at fossil fuel power plants. A task of the qualitative kind, which is also somewhat close the first grand type, can be found in M. A. Kurnaz and Arslan (2009, p. 78) (Figure 2)

Q4. The velocity of an object moving on a straight line under the influence of a single force, changes as in the velocity versus time graph. Tell the sign (+ or -) of the work done on the object by the force for each interval (AB, BC, CD and DE) and explain the reasons.

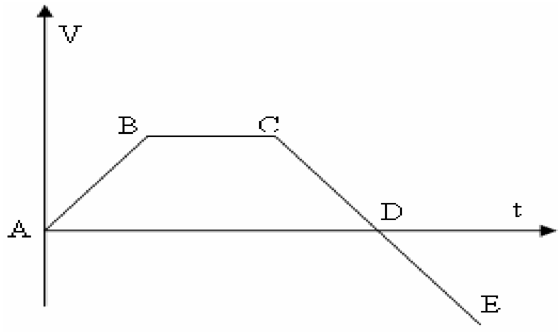


Figure 2: Example of second type task, with close relations to first type tasks

This question can be solved using at least two different techniques: τ_1 Using the fact that the change in velocity determines the acceleration, and thereby the force and the work (Utilizing Newton 2. law and the equation: $E = F \cdot \Delta s$, where F is the force and Δs is the displacement) When the work done by the force on the object is positive, it means that energy is transferred to the object, and vice versa. Another technique τ_2, is to consider more directly the velocity as a function of the kinetic energy of the object. If the velocity increases, the kinetic energy increases (and by the work-energy theorem, the work done on the object must have been positive). The technology θ associated with the two techniques involves a discourse in which work is seen as a mode of transfer between forms of energy, and mechanics of rigid objects provides the theory Θ, otherwise there would not have been such a direct link between work and kinetic energy (Jewett Jr, 2008).

The *third grand type* is related to the *human "use"* of the harnessed energy and the *challenges* it leads to. Environmental issues are central to these tasks, and they can be understood as representing a "society-related"-part of the energy topic. The focus is removed from energy as something that is transformed. Instead energy is referred to as something produced (e.g. by wind mills), and transported (in the power grid) to where it is consumed by some artefact under human control. Energy can be in "short supply", it can be "saved" and the energy efficiency of devices can be poor. Energy can be "carried" by different substances, some of them problematic, others convenient according to the use (e.g. fuel or electricity to power cars). Tasks in this category very often include the axiological component of energy usage, and quickly take the investigation outside a single discipline, and particularly outside the disciplines of science. Questions leading to tasks of this type are usually quite broad, e.g. like in Pearce and Russill (2005) where it is asked: How to address global climate destabilization by encouraging the use of compact fluorescent light bulbs? This quickly leads to value judgments about one kind of light bulb compared to other kinds of light sources. The invention or development of energy efficient lighting is indeed a response to societal needs. It may help solve CO_2 emission problems, but does it just create a mercury pollution problem instead? There are also environmental issues to consider including in the teaching of the energy-topic. It is clear that different disciplines will find different aspects of such an overall question more relevant to consider in teaching than others. How do such bulbs function? What is the quality of the light they emit? Why should you buy them, when they are more expensive than ordinary bulbs? These "derived" questions co-define the disciplinary interest, and the discipline's "ability" to answer it.

Context for this study

In this section I describe the teacher education layer as situated between its closest related layers of institutions. With reference to Figure 3, I place teacher education on layer 2, where it is "sandwiched" between lower secondary education (layer 1) and the universities in charge of tertiary education (layer 3). Danish teacher education takes place at institutions called "University Colleges" (hereafter abbreviated UC) which operate *administratively* independently of the two other layers. Each layer has its own ministerial regulations, and serves different needs of the society. To become a teacher in lower secondary schools, students usually attend 9 years in primary and secondary school, 3 years high school and 4 years at a UC.

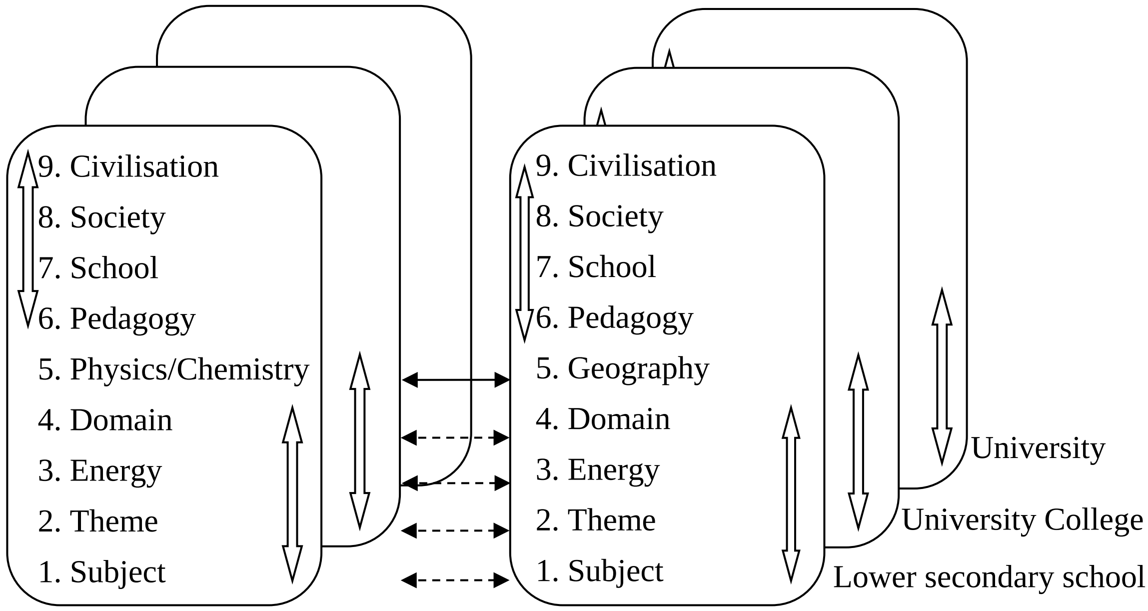


Figure 3: Model of the considered disciplinary ecologies

Students at UCs usually acquire competence to teach three disciplines in lower secondary school, and in this paper only two disciplines are considered: “Physics/Chemistry” and “Geography” which carry the same name on layer 1 and 2. “Physics [slash] Chemistry” is the name for a single discipline found only in lower secondary school and the UCs, and it covers a mix of physics and chemistry topics. I will specifically investigate how these two disciplines interact in the teaching module: “Energy and Climate” which was one of six bi-disciplinary modules developed as part of the Advanced Science Teacher Education project (ASTE-project) initiated in 2012 in Copenhagen.

The ASTE-project was set up to run an experimental teacher education program attempting to teach mayor parts of the disciplines of science and mathematics as a coherent whole.[1] The project is partially funded by the Lundbeck Foundation, a foundation that sponsors educational initiatives in the fields of the sciences. Funds from the foundation cover the development project, whereas the ordinary governmental subsidies that “follow” the students are used to run the education itself. The educational program is planned by a consortium consisting of the University of Copenhagen, University of Aarhus, University College UCC and the Metropolitan University College all represented in the “ASTE Steering Committee” which runs the daily affairs of the development project. In addition four lower secondary schools participate as practicum schools, and although they are not intimately involved in the development process, they do take part in some meetings where the experimental program is discussed. In the Danish teacher education context, the program is novel in trying to integrate disciplines in a substantial and systematic way, and in attempting to develop the program in more or less close collaboration between lower secondary schools, university colleges and universities (i.e. between the tree layers of the model). It is furthermore an innovation of the program to split the teaching of individual disciplines into smaller modules. It should be noted that the actual teaching in the program is to be done by educators from the university colleges, who therefore occupy a central role in the project, and as a consequence also in this study.

Methods

The data gathered for this study comes in the form of audio recordings of an extensive number of meetings from the planning of the ASTE-project. These recordings were inventoried and time indexed for reference. Written materials produced by working groups were collected, comprising drafts of curricula and electronic presentations, as well as selected e-mail correspondence. Written

[1] Approximately 30% of the workload, according to the application for external funding. (Goldbech et al., 2011)

documents also include applications for funding and ministerial approval. Quotations used in this paper are translated from Danish by the author. To supplement the above primary data sources, two separate interviews were undertaken. One with a representative from the ASTE Steering Committee and one with a University College professor who were closely involved in the making of the "Energy and Climate"-module. The interviews were semi-structured and involved a direct consideration of the examples of grand task types shown in the exposition of the reference model. This was done to structure the interviews so that they would reveal the developers vision in more depth than could be expected from an overall discussion that was not grounded in concrete ideas for teaching.

Results and Data Analysis

I begin the analysis from the upper levels of co-determination, working my way down towards the more specific implications for teaching. The intended interactions between the institutional layers are evident from the onset of the ASTE-project, as can be seen explicitly in the funding application to the the Lundbeck Foundation:

> "The development of the teacher education programme will be done in close collaboration between the university colleges and the relevant departments of participating universities. This will involve taking advantage of the strong research communities and facilities available at the universities and combining them with the experience and expertise of the university colleges to create a unique teacher education."
>
> "The university colleges provide the brunt of the teacher education and in-service training while university science and math educators will offer specific courses and excursions to both in-service teachers and teacher students." (Goldbech et al., 2011, p. 8)

This is interaction codified at the school-level of the co-determination scale. It is in its nature a general, formal statement of intention to build something together "across" the layers. There is even the idea to have educators from the university offer courses directly to teacher students. This was later made impossible due to influences from the society level:

> "The ministry would not give the ASTE project permission to run its educational program if it were not exclusively UC educators that conducted the actual teaching of the students" (Personal communication with ASTE Steering Committee Member, December 18th 2012)

Therefore I can see a certain disparity between the two major collaborators, where those from the UCs have the primary educative role and those from the universities act more as consultants:

> "It is basically a consultancy service which has to be utilized precisely and best possible" (ASTE Steering Committee member, Developers Meeting, June 18th 2012, Audio time index: 6:50-6:55)

Looking again to the level above school, I note further constraints on the educational program that influenced the project directly by ministerial decree at the society level; the consortium wanted to run the experiment twice (i.e. Two batches of students starting one year apart.) This was refused, as was a request to have the governmental subsidies released in small portions as each teaching module was concluded.(Søbro, 2012) This later fact generated rather severe constraints on the way each teaching module would be *assessed*, which meant for the "Energy and Climate" module that a written report should be handed in by the students, only to be evaluated at a much later time.

> "It has most certainly had influence on the structure of the educational program, that there has been speculation in the release of subsidies" (Interview with ASTE Steering Committee member, December 2012, Audio time index 13:49-13:55)

The structure and especially tests and examinations are known to condition even the most concrete teaching on the subject-level. (Cheng, 2000)

Given that the collaboration between the UC and university layer, as we have seen above, had to be less prominent in the actual running of the educational program, I now turn to the collaboration in the curriculum development process. In the case of the "Energy and Climate"-module, it did not always run smoothly:

> "With risk of stepping on somebody's toes, I have yet to experience in the ASTE-collaboration, that the university people have been able to contribute anything new. On the contrary we have used time to inform them of the conditions, constraints and praxis of teacher education, and the same goes for lower secondary education. This is in my opinion a waste of time, considering that they are not going to teach the modules of this program… therefore it is of outmost importance that it is made explicit what roles each partner has in this collaboration, and that the tasks and obligations we each get, are dependent on the unique competencies each has to offer." (UC collaborator to ASTE Steering Committee, email correspondence, June 12th)

Tension between collaborators is perhaps not surprising, but it testifies to a divide between the layers which gives credence to the underlying theoretical assumption that education is indeed strongly institutionally situated. It is also an expression of the field of tension (mentioned in the theory section above) that becomes apparent when the different layers are brought together.

Moving down the hierarchy of levels I find in the funding application more specific reference to the bi-disciplinary teaching modules, in particular one that refers to teaching of energy topics:

> "For the program we intend to develop the following interdisciplinary courses:

- Teaching energy and energy *supply* – covers main subject areas of geography, physics, chemistry and pedagogical subjects”

(Goldbech et al., 2011, p. 6, my italics)

In this is seen an explicit mentioning of teaching issues related to the third grand type of tasks, i.e. “energy *supply*” The headline for the module changed when the Ministry of Education were petitioned to allow the experimental program to run, there it was called: “Energy and Resources, Climate” (Graae et al., 2011) and finally it ended up as “Energy and Climate” in the developed curriculum(Goldbech et al., 2012b) The change of headline were regarded to caused by changes in the composition of people in the working groups and their emphasis on different curricular items from the ordinary (mono-disciplinary) curriculum:

> “There is no doubt that the thing about the changing headlines is because different persons get them in their hands and try to assign meaning to them.” (Interview with ASTE Steering Committee Member, December 18th 2012, audio time index: 26:10-26:20)

Anyway the final document is a direct enlargement of the former giving more description regarding goals, contents and working methods. It is clear from the “justification” given for the module, stated in both versions of the curriculum draft, that this new module is created by joining at the discipline level. Both original disciplines, from ordinary teacher education, are explicitly mentioned, and I note that they occupy positions on each end of the continuum presented in the reference model, which can also be corroborated from other sources:

> “Physics/Chemistry supports Geography through introduction to, and understanding of an assortment of fundamental disciplinary concepts and practical methods. Geography supports Physics/Chemistry through concrete examples of the use of physics and chemistry outside the boundaries of lower secondary school, and through perspectives regarding other scientific views, specifically human-geography views”
>
> (Energy and Climate - introduction to the bi-disciplinarity of the module, presentation by the UC developers, June 18th 2012)

Physics/chemistry contributes focus on the first grand type of tasks, whereas geography has focus on the third grand type.

Looking below the discipline level I note the developers intention to foster their students’ interest in the sciences by using key questions of the type proposed by Wolfgang Klafki (i.e., “epochaltypische schlüsselprobleme”) (Klafki, 1994). This can be seen as originating on the pedagogy level, but it has direct consequences on the theme level:

> Immediately I could imagine starting by showing [the students] something, perhaps not exactly this movie, but never the less: Al Gore's "An Inconvenient Truth". Start with it and say: "Okay, what is this about, where does it come from" Or show them the first papers by Henrik Svendsmark about sunspot theories … something that provoked them; you could also put forward a conflict of interests." (Interview with UC developer, December 18th 2012, Time index 18:14-18:58)

While this influence from pedagogy to theme level originates inside ecologies at the same layer, there is a vision by the developers to use external "milieus" for pre-service teacher learning to a greater extent, which is directly influenced by the cooperation with the university layer (here regarded not as an educational institution, but as a research institution):

> "we have written in … [Energy and Climate], that we will use external milieus for learning - and we would very much like to get out and see laboratory facilities, out hearing[sic], meeting the milieu, with the pre-service teachers" (UC collaborator, Developers Meeting, June 18th 2012, Audio time index: 19:53-20:04)

This is to be done as part of actual teaching activities (not just extra-curricular informal visits or the like of that), which places this as an influence from the school level of the university layer to the subject level of the UC layer. The pre-service teachers have to meet "ordinary" scientists, know and talk to people "doing science" in order to be able to convey the study of science as a real educational possibility to lower secondary school pupils:

> "If they [pre-service teachers] also think: "that is one weird scientist", then they have a very hard time motivating the pupils" (UC collaborator, Developers Meeting, June 18th 2012, Audio time index: 20:49-20:55)

Turning the attention to perspectives on "energy"-topics as perceived by the different UC-disciplines, I can showcase the way the UC-layer perceives teaching on the two adjacent layers. The "Energy and climate"-module has three mandatory curricular items that explicitly mention energy, and they are all carried over from the official (ordinary) teacher education curriculum:

- Physical geographic knowledge, theories and problems, which means physical geographical processes and patterns of distribution as a result of matter- and energy flow in nature
- Energy, energy forms, energy conversion and energy flow
- Resources, energy supply and chemical production

(Goldbech et al., 2012b, p. 50)

The first is from geography, the two others from physics/chemistry, and I note that the most literally direct overlap is "energy *flow*", interesting because the flow concept has previously been identified as a bridging concept when trying to integrate several disciplines (Wake, 2011). Resources and geographic knowledge goes well together, but only for some kinds of resources, and as seen above, "resources" were at some point taken out of the headline for the module.

> "When we talk about resources, it can be everything, it can be cobber or water, anything really, and it doesn't necessarily have that much to do with energy … [but it has to do with] which forms of energy supply are most relevant, meaning hydropower is relevant in some places, i.e. the geographical placement is very important regarding which energy resources you can utilize" (Interview with UC-developer (physics/chemistry), December 2012, Time index: 1:55-2:55, my italics)

This shows how knowledge from the two disciplines is thought to be combined and the quote gives an idea of how that may affect the sector levels and below, to form the essence of bi-disciplinarity (figure 4):

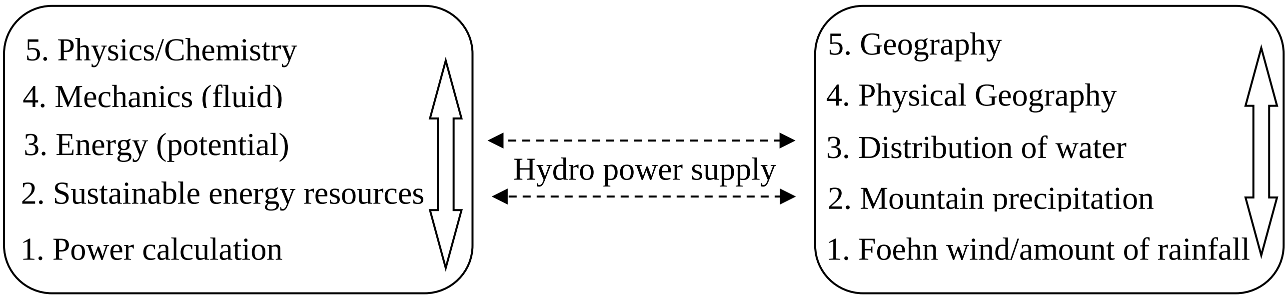


Figure 4: Example of bi-disciplinary interaction inspired by above quotation

Energy *supply* is central in the above quote, and I note that it alludes mostly to tasks of the third grand type from the reference model. The societal and environmental considerations are at the core of the interaction between the disciplines (indicated by horizontal arrows in figure 3), something which is not readily apparent if you only look at the disciplinary ecologies separately. Furthermore I note that elements of the second grand type of tasks are likely to enter the teaching, but it does not seem that prominent, something which is also reflected in the chosen curricular items, and in the next quote below.

Energy *supply* is believed on the UC layer to be central to teachers at the lower secondary school layer:

> "I do know how many of them [lower secondary school teachers] do, at least how some of them do: There is a lot [teaching], which is about how energy is distributed from a power plant, a windmill, to the consumer … Then there is a lot about saving energy, not so much why, but it is something you have to do. And then there is a lot about "playing" with energy - meaning heating something by burning something else, and that kind of

> thing, … there is not that much teaching of energy as a concept.” (Interview with UC-developer (physics/chemistry), December 2012, Time index: 22:47-23:34)

In contrast, the first years of university teaching is regarded as opposite:

> “… in teaching it is simply fundamental concepts, now we define kinetic energy, potential energy, mathematically based on the laws of gravity and so on. So there [at the university] you get those very fundamental basic concepts firmly rooted… and you look at entropy and energy of many different forms, but only in their most basic appearance. … It is only later, at rather advanced courses you start looking at it [energy] as part of other things…” (Interview with UC-developer (physics/chemistry), December 2012, Time index: 24:00-24:39)

The conclusion is that education at the lower secondary layer is seen as mainly concerned with tasks related to the second and third grand type, whereas the university layer is seen as dealing mostly with the first grand type of task. Both layers are regarded as having some consideration of the second type, but the continuum quality of the reference model does not lend itself to establish a rigid demarcation, at least not from the collected data. Educators at the UC layer perceive themselves as trying to combine the differences that position the two other layers at opposite ends in the reference model.

Discussion

Looking closely at institutional interplay is in danger of turning a didactical study into a “history of science education”. When one looks at the planning phase of an educational program, as is the case for this study, there is a natural detachment from particular and therefore more easily discernible didactical challenges. This leads the study to consider pre-didactical phenomena those nature is less concrete than e.g. didactical acts carried out in the classroom. In this way the present study is only looking at one part of a process and it remains to be seen what will actually happen when the “Energy and Climate”-module is executed. Does the actual teaching match up with the intentions?

Furthermore it would improve this study to triangulate the findings with investigations of teaching materials from each of the layers, and expand the interviews in order not to see the interplay between layers and disciplinary ecologies exclusively from the stance of the UC layer.

One can speculate why the second grand type of task do not figure that prominently, and a hypothesis is that Danish teacher education, both regarding educators and pre-service teachers do not recruit from the more technically inclined sections of the educational system, e.g. technical universities and technical upper secondary schools.

A final challenge worth considering in this study is the known difficulty to place science disciplines clearly in the hierarchical structure of didactic codetermination. There is not the same consensus, or perhaps nature of the science disciplines as in mathematics, which introduces a degree of arbitrariness when seeking to be specific about the lower levels of determination. One example is as stated earlier, where to place energy topics at all? I judged it to be on the sector level, but one of the interviewees argued for its placement on the domain level. This is a problematic issue for the model of didactic co-determination.

Conclusion

The vision of multidisciplinary science education, which lies behind the planning of the showcased teacher education, can be analyzed by tracing influences from one level and layer to another in the expanded model of codetermination. The influences stand out clearly when their investigation is carried out by focusing on one common topic; energy, which is central to both disciplines involved, as well as central to the three institutional layers. The state of research on energy teaching enabled me to build a reference model in ATD terms which in turn made the focus possible.

It has been argued that the UC layer played the central role in the development of the “Energy and Climate”-module in ASTE and it was apparent that conceptions and opinions of the adjacent disciplines and institutional layers shaped the developers’ vision of envisaged curriculum. The institutional layers are perceived to prefer teaching praxeologies from different parts of a continuum characterized by the grand task types, as described in the reference model. Summarizing it roughly, the university layer is seen to prefer the first grand type of tasks, whereas the third grand type is considered prevalent at the lower secondary level. The presented reference model characterizes the teaching of energy topics according to conceptual, procedural and axiological aspects, as well as scientific, technological, societal and environmental concerns, where the order in which these aspects and concerns are mentioned, also signifies the continuum of task types.

The planning of the bi-disciplinary “energy and climate”-module in ASTE were primarily influenced by the university college layer. This was due to institutional constraints originating on the society level, constraints that specifically worked against a greater and more direct influence from the university layer. The ecologies of Physics/Chemistry and Geography were planned to support each other at the disciplinary level, by representing a preference of respectively the first and the third types of tasks. The layered model proposed gave tools to analyze how the disciplinary ecologies were thought to interact on the sector level and below, forming through the example of “hydro power supply”, a more concrete picture of how the multidisciplinary interaction is believed to take place due to influences from both levels and layers.

The emergence and institutional co-determination of sustainability as a teaching topic in interdisciplinary science teacher education

Abstract: This paper takes an institutional perspective on the topic of sustainability in order to analyse how this 'idea' enters science teacher education through an interdisciplinary approach. It shows how the development and implementation of a course for Danish pre-service teachers was conditioned and constrained by a complex web of interactions in and among the teaching disciplines of Biology, Geography and Physics/Chemistry and among the institutions of school, teacher college and university. The data collected are used to identify influences among the disciplines as well as disciplinary differences, conceptualised through a new reference model that separates the analysis from the usual sustainability dimensions. The findings reveal how sustainability as a teaching topic can be a unifying idea in an interdisciplinary setting. Disciplinary differences evidently impact course planning and implementation significantly, but not exclusively. By elaborating on the interactions between these circumstances, the paper provides insight into the processes of didactic transposition.

Keywords: sustainability, science education, didactic transposition, institutional perspective

Introduction and research questions

Over the years, a good number of studies conducted within the educational research community have examined how educators perceive and understand sustainability issues. Sustainability is understood through various lenses, including people's beliefs and attitudes (Cotton, Warren, Maiboroda, & Bailey, 2007), diverse 'ad hoc' conceptions, such as *resources* or *justice* (Reid & Petocz, 2006), and a 'conceptual understanding' that has environmental, economic and social sustainability *dimensions* (as they are termed within the United Nations, see e.g. Drexhage & Murphy, 2010). These three dimensions are, perhaps, the most widely accepted ways of differentiating sustainability. In a quantitative study Borg, Gericke, Höglund, and Bergman (2013) showed that Swedish upper secondary school teachers had different understandings of sustainability depending on the subject they taught. The cause of these differences is, however, unknown: Can different educational and disciplinary backgrounds account for the fact that educators tend to emphasize only certain dimensions of sustainability? Or is their choice of emphasis a direct consequence of the curriculum they are required to teach their classes? Could the differences primarily be rooted in conditions outside the education system itself? The latter two questions are as relevant as the first, because definitions of sustainability are contested and closely related to policymaking (Dobson, 1996; Jickling & Wals, 2008).

Borg et al. (2013) were unable to 'get behind and reveal the underlying reasons for the subject-bound differences', and therefore recommended 'further interview studies, which starts from teachers' conceptions and works back to the three dimensions' (Borg et al., 2013, p. p.546). The present paper aims to follow this recommendation, at least as regards science teacher educators, but will go methodologically deeper by supplementing such interviews with additional data sources and employing a theoretical framework that takes the institutional situatedness of teacher educators as the prime explanatory variable.

The paper centres on a case study of an interdisciplinary pre-service teacher course that addressed sustainability issues. (See e.g., Mebratu, 1998, for a historical and conceptual review.) The issues included the broader concepts of sustainable development principles and practice as well as educational issues like environmental education and education for sustainable development (See e.g., Cotton et al., 2007, p. p. 581 for a discussion of conceptual differences.). These courses take place in a Danish context as part of the Advanced Science Teacher Education (ASTE). The ASTE education programme aims at qualifying prospective lower secondary school teachers to provide science and mathematics education that transcends the usual subject boundaries. The study focuses on how the case course, entitled 'Sustainability – energy and foodstuffs', was developed and implemented, and special attention is given to teacher educators from the university colleges (UC) that participated in developing and implementing the course. University colleges are the institutions in which Danish lower secondary school teachers receive their pre-service education, and thus constitute an *institutional layer* separate from (research) universities and lower secondary schools (LSS).

The case presented in this paper involves three *teaching disciplines*: Biology, Geography and Physics/Chemistry, which pre-service teachers study at university colleges (UC) and subsequently become licensed to teach at lower secondary schools. In this paper, these teaching disciplines are capitalized when referring to the UC layer. When not capitalized, the terms refer to the general notion of disciplines as fields of study taught at any layer of the education system, while the term "subject" is used exclusively to denote the teaching disciplines taught at the LSS layer.

The above considerations lead to the following research questions: What characterizes and causes the differences in UC educators' perspectives on education relating to sustainability? Specifically, how do these differences interact and thus influence the planning and implementation of pre-service science teacher courses?

This paper seeks to answer these questions by tracing the influences in and among teaching disciplines and institutional layers that affected how the interdisciplinary pre-service teacher course on sustainability was developed, planned and implemented.

Theoretical framework

The anthropological theory of the didactic (ATD) has been developed within the realm of mathematics education research since the 1980s (Bosch & Gascón, 2006, 2014; Chevallard, 1992, 1999), but in recent years researchers have utilized ATD in science education. (See e.g. Dorier & García, 2013; Gericke, 2009; Girault, d'Ham, Alturkmani, & Chaachoua, 2011). A prime theoretical component of ATD is the notion of *didactic transposition*, which highlights how the characteristics of knowledge[1] differ when regarded in different institutional contexts. Knowledge can, for example, be understood to reside in some particular institutional *ecology*[2], which imbues the knowledge with certain characteristics. Regarded in another institutional context, however, this knowledge is re-interpreted to become meaningful within the new context, i.e. *transposed*, like a musical score transposed to another key. The knowledge is recognizable yet different. When knowledge is transposed for the purpose of educating someone, the process is called *didactic*, and the need for this process becomes particularly evident as knowledge moves among institutions that produce and disseminate knowledge. (Figure 1):

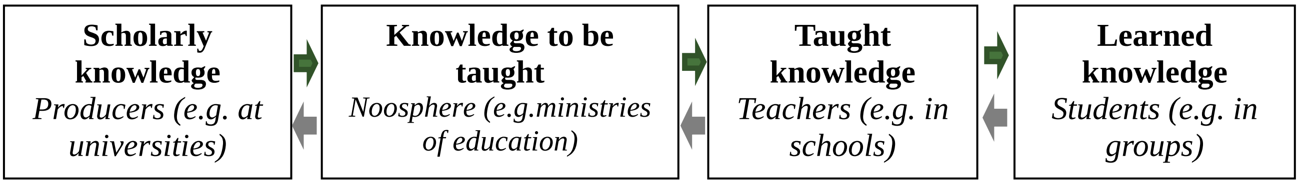


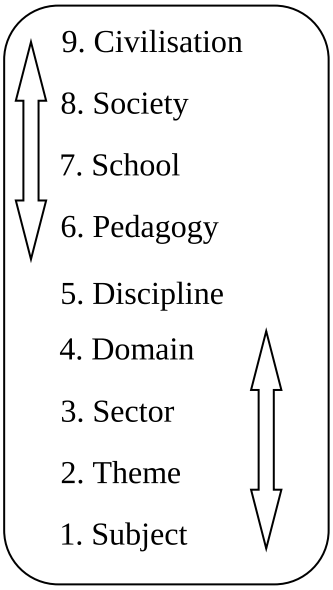
Figure 4 Principal steps of didactic transposition, with examples of institutional contexts. The *noosphere* is anyone voicing opinions about what knowledge should be taken up in education.

In general, institutions can be understood quite broadly (Sierpinska, 2006). They can range anywhere from a team of three science teachers who have been close colleagues for ten years to all the employees of a university chemistry department. It follows that individual people can belong to different institutions, as well as that one institution can be embedded in others. This paper considers

[1] ATD *includes* practice, i.e. the use or application of knowledge in its epistemology of knowledge.

[2] The ATD meaning of *ecology* here refers to the institutional settings in which the knowledge 'lives'. For this reason words derived from ecology, e.g. ecological sustainability, has been avoided throughout the paper.

the following institutions: a given society's educational institutions (Danish universities, university colleges and lower secondary schools) and institutions of particular teaching disciplines (geography, biology, physics/chemistry) taught at any of the society's educational institutions. An institution of a teaching discipline is a community of people that see themselves as stakeholders in the teaching of a discipline. The community has texts, organizations, common methods and views, etc. (See also Winslow & Grønbæk, 2014, p. p. 66). In ATD ecologies of knowledge can be described using a generic *scale of levels* (Chevallard, 2004), where one level influences what happens the others, while no level has any particular preference over another. Figure 2 presents the generic name of

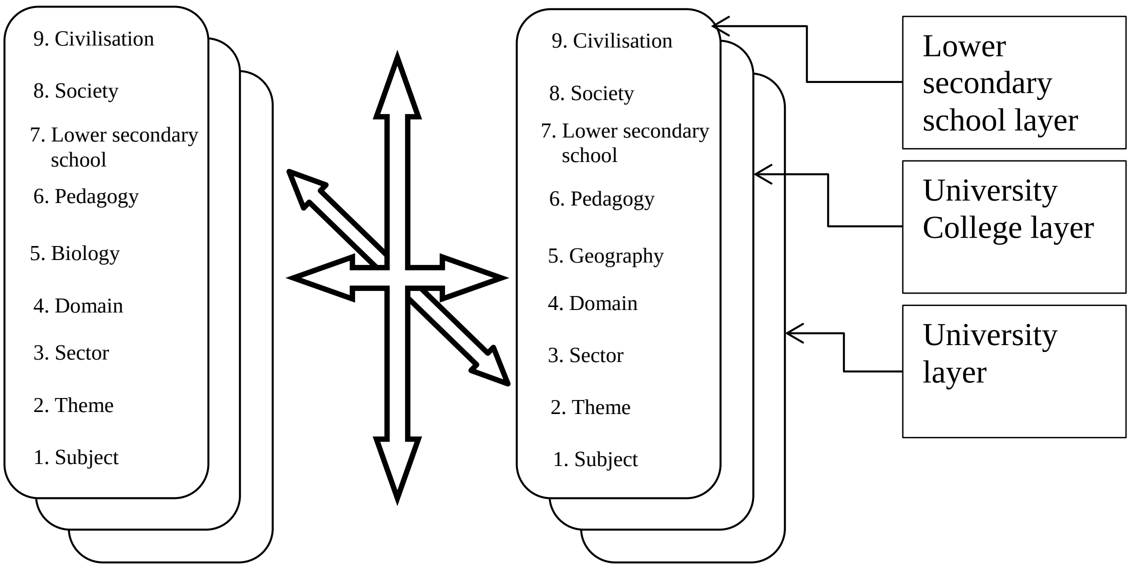


each level

The levels of the scale co-determine each other. For example, if the discipline is biology, then the *theme* of lessons can hardly be 'movement of celestial objects', and only a certain range of pedagogies may be regarded as appropriate for the biology ecology. Although the ecology description is only truly meaningful when most of the scale levels are specified, for the sake of clarity, this specificity is only introduced gradually as the paper progresses. Co-determination is bi-directional (upwards and downwards), but constraints from the upper levels often predominate. The scale of levels is chiefly intended to identify and locate conditions and constraints coming from outside a particular position in the ecology. When dealing with research on educational settings spanning several teaching disciplines, one can expand this model to scrutinize how the disciplines influence each other. Figure 3 shows two scales of levels placed side by side (See also K.

Figure 2 Generic names for the levels of co-determination (Chevallard, 2004) Notice how "subject" here signifies the very particular "question" in e.g. a teaching sequence. (Not to be confused with the LSS teaching discipline)

Rasmussen & Winsløw, 2013). Taking into account that teaching disciplines inhabit different *layers* of the education system, one can further develop the model to incorporate how these layers superimpose each other, as seen in Figure 3. It follows that adding further ecologies, defined at



some of the remaining levels of the scale, would render graphical illustration difficult.

Figure 3: Two disciplinary ecologies with three layers. (Here illustrated with the layers under consideration in this paper) Fat arrows indicate that influence can work among any level, discipline or layer.

To use the framework of didactic co-determination, one has to apply the 'detachment principle' (Bosh, 2012) and elaborate on the position of the researcher outside of the institutional contexts under scrutiny. For this reason, ATD operates with the notion of *epistemological reference models* (ERM), which enable one to describe the knowledge and practices involved in the didactic transposition process without implicitly elevating any given institution to a privileged position (Chevallard & Bosch, 2014). For the purposes of this paper, the next section provides, an ERM that fits general 'ideas' like sustainability, bearing in mind that such models are never truly complete.

An epistemological reference model to deal with the teaching of sustainability

The Brundtland report from 1987 provides a classic starting point for defining sustainable development in relation to *growth* (WCED, 1987), a definition that has sparked ongoing contention, especially in relation to economic growth (Bonnett, 1999; Jickling, 2005). Because the juxtaposed terms 'sustainable' and 'development' are notions that apply in environmental, economic and social sciences alike, the term ‘sustainable development’ carries qualities that at once are interdisciplinary and put the notion in a field of tension. As mentioned in the introduction, sustainability is consensually seen as having environmental, economic and social *dimensions* (Borg et al., 2013; Summers, Childs, & Corney, 2005, p. p. 629). While these dimensions constitute a useful step in the creation of a reference model, they are laden with intellectual baggage from the disciplinary or scientific fields carrying the same names. Therefore a further step is necessary to enable the subsequent analysis. Following a proposal by Doménech et al. (2007), which deals with the teaching of ‘energy-issues’, the idea in this paper is to similarly view the teaching of sustainability in relation to a continuum between three aspects: the *conceptual* aspect, the *technological/procedural* aspect and the *axiological* aspect. (See also K. Rasmussen, 2013). Teaching with an emphasis on conceptual or procedural aspects is well known in both science and mathematics education research. (See e.g. Heyworth, 1999; Hiebert, 2013).This epistemological reference model couples the procedural aspect with the technological as a means of emphasizing that procedures often manifest in human artefacts. Getting to know these artefacts is often part of teaching - e.g. knowing the makeup of a machine and how to operate it. The axiological aspect has to do with value judgements, because such considerations enter into teaching (Poole, 1995); for example, the topic of nuclear fission often includes references to the positive and negative benefits for society. The following example regarding the issue of *growth* may help to illustrate the three various aspects used in this model.

The issue of *growth* may crop up in data (e.g. in a video recording) obtained from a teaching situation that relates to sustainability. The teacher may address the growth issue from different aspects. He or she may deal with growth primarily as a quantity, an economic entity, for example, whose various definitions are debated (the conceptual aspect). The teacher could also treat growth as a set of figures to be calculated and compared for different countries by means of particular algorithms, methods (procedural aspect) or artefacts (technological aspect). Finally, the teacher might focus on whether a certain case of economic growth is desirable to different interest groups, contrasting the monetary and non-monetary values of natural resources (axiological aspect).

The ERM is general and applies to ‘big issues’ in educational curricula, like ‘energy’ and ‘sustainability’, as is the case in this paper. Topics that lend themselves to interdisciplinary consideration (e.g., the 'bridging concepts' coined by Wake, 2011) seem particularly well suited, but the domain boundaries of the model will not be pursued further in this paper. The model can be illustrated by a triangle with each of the aspects at one of its vertices (see Figure 4).

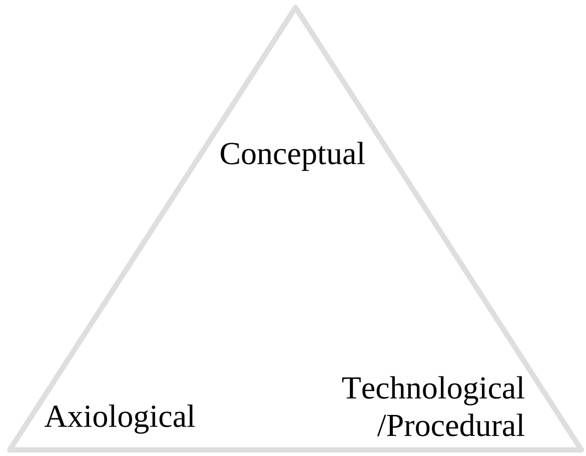


Figure 4 Illustration of the general epistemological reference model. A specific piece of data can be placed in the continuum spanned by each of the aspects placed in the corners.

Sustainability taught in an interdisciplinary setup would ideally focus on the *connections* between teaching disciplines, in which case environmental, social and economic dimensions would be a less ideal frame of reference, as these dimensions are inherently closely associated with single disciplines. Using those dimensions would be like judging the beauty of the countryside between three cities by comparing fields and cottages with the parks and buildings in each city. The proposed ERM provides the needed detachment.

Context

The ASTE project developed the case course 'Sustainability – foodstuffs and energy' over an extended period of time starting in early 2012. The project was first run from January to May 2015. The ASTE partners include two universities, two university colleges (abbreviated UCC and UCM) and eight partnership lower secondary schools (the exact number of involved schools depends on the number of pre-service teachers enrolled each year). The course development process consisted of a series of meetings held to formulate the entire ASTE curriculum and thus to select the combinations of curricular items from the constituent teaching disciplines and to compose course descriptions – six interdisciplinary courses and thirteen mono-disciplinary ones.[3]

The development period was so long because the ASTE project started under one national teacher education act (LU07) but came under another (LU13) in 2013, the latter having a very different

[3] Hereto came a number of courses on general pedagogic subjects, which were toned slightly to align with the science focus.

structure. Therefore, the project group had to scrap parts of the originally developed ASTE curriculum. This precipitated a one-year delay in its implementation, and project group members from the two university colleges and one of the universities were tasked with reformulating the curriculum. The reformulated ASTE teacher education ended up being composed of four interdisciplinary courses, which must be considered the core of ASTE, and nine additional mono-disciplinary courses, six courses on general pedagogy, three practicum periods and a bachelor project period. As the implementation of the course approached, subsequent meetings were held to plan the actual lessons, which amounted to about 72 lessons of 45-minutes duration spread over 13 weeks with four to six lessons per week.

All three institutional layers – university, UC and LSS – participated in the meetings concerning overall curriculum formulation, each tasked with the same role of giving input to the process from its perspective. In the detailed planning and implementation of lessons, the UC layer shouldered the primary role, while the university layer was a 'resource' or sparring partner, and the lower secondary school was reduced to a role of supporting the pre-service teachers when in practicum.

Approximately twenty pre-service teachers enrolled at each of the two university colleges where the core interdisciplinary courses ran in the same semesters.

Three educators at each UC – one from each constituent teaching discipline – implemented the case course, which was one of the four core interdisciplinary ones. At UCC all three educators had participated in the entire development and implementation process, while at UCM this was only the case for the Physics/Chemistry educator. The Biology educator had participated in the process since the Danish education reform took effect, and the Geography educator joined ASTE when course implementation began.

Methods

The primary data source for this paper is approx. 12 hours of audio recordings from meetings regarding the reformulated project, before, during and after the course was implemented. These meetings were triangulated with six interviews held in the last three weeks of the course implementation period – one interview with each of the UC educators teaching the course. The interviews are described below. In addition, some 20 pages of central documents (lesson content plans, email correspondence and developers' notes) have been included in the coding (see below), while the extensive material used and developed by educators and pre-service teachers alike during the course implementation has only been cursorily reviewed.

The interviews were semi-structured, following an interview guide developed to probe the interviewees' perspectives on sustainability and interdisciplinary teaching in the specific case course. Questions focused on established conceptions and vocabulary regarding sustainability (dimensions, action competence, etc.) and on how the interviewee saw sustainability as an issue in education at schools and universities.

Audio recordings (meetings and interviews) and central documents were filed and inventoried with the qualitative data analysis software Nvivo10. The inventorying process consisted of making notes for each coherent passage describing the contents. This generated roughly one note per two minutes. These notes constituted the basis for the coding process, in which two sets of codes were used: one set to identify expressions of sustainability in terms of the ERM, i.e. three codes with the same brief designations used in the reference model, and the other set to identify expressions of influences among the scale levels, teaching disciplines and institutional layers. The layer influence was separated into two subcodes, one for school and one for university, respectively. The soundness of the coding procedure was tested by having eight co-workers code two randomly selected samples of transcribed audio data. This gave rise to negligible concern for reliability.

The data analysis method employed is in accordance with theory-driven thematic coding (Boyatzis, 1998). This means theory informs what is looked for in the data, and the themes developed from data are subservient to what the theoretical lens is able to capture. Thus, the data is much richer than the analysis is able to convey, meaning that thematics other than the institutional and disciplinary ones investigated here could in all likelihood be extracted as well. However, the strong theoretical component is deemed necessary to investigate the research questions.

A final remark on the data concerns the apparent scant focus on the perspective of the pre-service teachers attending the course. Apart from the above-mentioned cursory review of in-course materials, a questionnaire was given to the pre-service teachers two weeks into the course. Apart from being a translation, the questionnaire was identical to the one used by Pedretti, Bencze, Hewitt, Romkey, and Jivraj (2008) to gauge the respondents' confidence, motivation and willingness to teach sustainability issues as a licenced teacher. The pre-test showed overwhelmingly positive support for having sustainability as the central issue in science education, and the subsequent post-test, performed two weeks after the course finished, showed that the few qualms initially held had been dispelled.

Other data focusing on pre-service teacher perspectives include field observations of lessons (four regular lessons at each UC) and four hours of a project presentation session at UCC, while the same session at UCM was audio recorded. Finally, it can be noted that UC educators personally discussed and evaluated the course together with the pre-service teachers, and the insight gleaned shows up in interviews and post-course meetings.

While this data corroborate the primary data, focusing on the perspective of the UC educators, it has deliberately been placed in the background because the pre-service teacher perspective is beyond the scope of this paper, other than what comes to the foreground through the deliberations of the UC educators.

Findings

This part is divided into five sections. With reference to the research question, the first two sections deal mainly with the causes for different perspectives on sustainability in relation to the case course. The sections focus on the genesis, i.e. the didactic transposition that determined the makeup of the course. The transition to 'knowledge to be taught' and the transition to 'taught knowledge' are the processes under scrutiny here. The last three sections deal with the effects on course planning and implementation by tracing the influences in and among the disciplinary ecologies and with respect to institutional layer considerations. This is done to analyse how the interdisciplinary and inter-institutional endeavours manifest themselves, and deals, as such, mainly with the transition to 'taught knowledge' as well as with 'taught knowledge' itself.

The emergence of sustainability as a central issue for an interdisciplinary teacher course

The course title 'Sustainability – foodstuffs and energy' emerged before the course development process. The title has roots in the previous ASTE education course description (developed under LU07, see context section), entitled 'Agriculture and Foodstuffs', in which only the two teaching disciplines of Geography and Biology were to interact (ASTE material, April 2012, Theme 3). The course described several of the curricular items also selected for the case course, but they were not explicitly designated as originating from either of the two disciplines, information, which in the contrary, was clearly delineated in the case course curriculum text. Further, the 'Agriculture and Foodstuffs' course description was one coherent whole with no particular reference to the constituent teaching disciplines, whereas the description created for 'Sustainability – foodstuffs and energy' described each teaching discipline's contribution to the course separately. In 'Agriculture and Foodstuffs' the paragraphs on purpose and objectives made no explicit reference to sustainability, but related issues, such as conflicts of interest and action competence, were raised. A question certainly presents itself: Why this regression to something that integrates the teaching disciplines less seamlessly? The decision at the society level of the UC layer to restructure teacher education constrained ASTE in several ways: The ASTE education could not be an experimental education with autonomy for all its elements; rather, it had to follow certain national provisions, specifically a number of curricular items had to be pre-allocated to common, nationally defined courses, thus making them unavailable for interdisciplinary combinations. Courses also had to be of the same size – 10 ECTS (European Credits Transfer System), which blocked the idea of simply merging two of the original (LU07) courses, ‘Energy and Climate’ and ‘Agriculture and Foodstuffs’ into one under the heading of sustainability, thus bringing together all three science teaching disciplines. This would be readily possible if the course ‘weight’ were 20 ECTS, as suggested by a representative of the university layer. (ASTE Working Day, Part 1, May 2013; Time index 50:10-51:20)

During the necessary reformulation in May 2013, it was agreed to rewrite the curriculum formulations without necessarily attempting to salvage formerly made combinations of teaching disciplines or curricular items. However, as can be seen from the previous paragraph, the intellectual baggage continually influenced the debate. One person said, ‘But would there be any point, anyway, in quickly reviewing these, the six [original interdisciplinary courses], and then selecting the four we could continue to work with?’ (ASTE Working Day, Part 1, May 2013; Time index 15:52-16:00)

The meandering path to sustainability as the central notion of the course often gyrated along with other notions like conflicts of interest, globalisation, and in particular *foodstuffs*, which turned out to be a catalyst for integrating the Physics/Chemistry teaching discipline into the combination of Geography and Biology. The UC educator specialising in Physics/Chemistry could easily fit a lot of ‘his’ curricular items under a heading containing foodstuffs: ‘This about foodstuffs is quite suitable’ (ASTE Working Day, Part 1, May 2013; Time index 38:40-38:42). This fitting of curricular items represents an exertion of influence among the disciplinary ecologies at the domain or sector level, but a certain institutional layer influence also became manifest on numerous occasions: The UC educators in the three science teaching disciplines were all familiar with a book entitled ‘Food for millions’(Thostrup, Husted, & de Neergaard, 2013), which was written by university academics. Sustainability was the central issue of this book, produced outside ASTE, but nevertheless at one of the participating universities, and it was consistently referred to at every meeting that led to the formation of the realised curriculum text. Although never mentioned as the central material to be used in the course, the book clearly served as a source of inspiration and as evidence that sustainability could serve as the pivot for the course.

The process of reformulating the ASTE curriculum in May 2013 was largely a ‘cut and paste’ exercise (also thus dubbed by the participants at the reformulation meetings). The curriculum items left over from the national courses were physically cut out of a sheet of paper and pieced together under tentative headlines on another sheet of paper! The document emerging from this process was called ‘Sustainability’, with ‘foodstuffs and energy’ as a subheading. While the presence of foodstuff is readily understandable from the data, the reason for mentioning energy is much more subtle. One hypothesis is that it supports the incorporation of the Physics/Chemistry teaching discipline, but data indicates the original influence came from the Geography teaching discipline in consideration of ‘energy loss’ in the food chain as a way of quantifying sustainability. (ASTE Working Day, Part 2, May 2013; Time index 18:52-36:18) Having the ‘energy’ issue as part of the case course provoked several demarcation debates in relation to the ‘Energy and Climate’ core module, where this topic was much more centrally placed. The debate was resolved by using a narrow interpretation (energy related to foodstuffs) for the case course and a broader interpretation (energy related to resources and the general concept) in the ‘Energy and Climate’ course. (ASTE Sustainability Module Meeting, February 2014; Time index 9:58-17:51)

Teacher educators’ perspective of sustainability – disciplinary affiliations

Sustainability is a broad term encompassing many facets of life and human interaction and thus a quality around which people from different disciplines can easily rally. The UC educators in the ASTE project each represented a single teaching discipline when partaking in the development process. Although a few were qualified in two of the three teaching disciplines brought together in the case course, at the meetings they each stood as the voice of only one of the existing teaching disciplines in the institutional setup. Did the perspectives voiced on sustainability differ?

In the data material analysed, 37 content entries were coded as expressions of the reference model, 13 of them related closely to an axiological stance, 16 to a conceptual stance and eight to a technological/procedural stance on sustainability. First, the axiological aspect will be addressed: By referring back to the disciplinary background of the educators expressing each piece of coded content, one can see that seven come from Physics/Chemistry, and three from Biology and Geography, respectively. However, a closer look at the coded entries for Physics/Chemistry shows that three of the seven in that teaching discipline express axiological aspects as ‘important’, but only when firmly connected to the other vertices of the reference model. An example: The idea of global development is valued in Physics/Chemistry when coupled to the technological aspect:

> Global development [is an issue if understood as the] distribution of technology, that is, if you can develop some very cheap technological solutions, which are able to fundamentally change the social and economic conditions in poor countries. (Interview with UCM educator, physics/chemistry affiliation, Time index 15:20-15:36)

A similar need to invoke a special connection to conceptual or technological/procedural aspects when dealing with axiological matters does not arise with the other two disciplines.

As for expressions of conceptual aspects, the distribution is three from Physics/Chemistry, seven from Biology and six from Geography. Physics/Chemistry educators often alluded to bringing in sustainability on a solid basis of core disciplinary concepts like ‘energy’ and ‘substance cycles’. Indeed making connections between the sustainability concept and core disciplinary concepts were expressed as a central concern:

> *I have put special emphasis on the physical and chemical aspects, meaning that when we work with substance cycles, we talk a lot about the idea of ‘cycles’ and underline its importance to the sustainability concept. So this is much about chemical understandings*. (Interview with UCM educator, Physics/Chemistry affiliation, Time index 26:45-27:00).

The Biology educators often talked in terms of conceptual learning, but had a difficult time getting to grips with which concepts should be central. On the one hand, some core concepts stemmed from biology, e.g., food chains, growth efficiency and ecological pyramids, while others originated from the realm of sustainability as a field of study in itself: ‘cradle to cradle’, resilience and the ‘ecological footprint’. One of the UC educators from Biology remarked:

> *I tried to find some core disciplinary content elements, which I believed were very important for them [the pre-service teachers] to know. This goes somewhat against what you [another UC biology educator] say when you state that you have departed from teaching biology [per se], but teach how to teach it. To be honest, I found these to be core concepts that I would like them to know*. (ASTE working day June 10, 2015, Time index 8:50-9.28)

The question for the educators was which concepts to put under the others, a question that mirrors the central dilemma of interdisciplinary teaching: Should the study of interdisciplinary issues make us wiser about the individual teaching disciplines, or should the study of teaching disciplines enable us to better understand their interdisciplinarity? While the answer is most likely dialectic between these two points, it is clear from the data that non-subject-specific concepts dominated the discourse. Indeed, how could it be otherwise? The educators from all teaching disciplines particularly referred to the conceptual notion of ‘cradle to cradle’, which fits well with the concept of cycles mentioned in the above quote, whereas only Biology and Geography educators commonly referred to the ecological footprint. Conceptually, it seems that Biology and Geography educators had more common ground and were also most comfortable using the traditional dimensions of environmental, economic and social sustainability. These two teaching disciplines express a close relatedness to environmental concepts, but at the same time assign equal importance to the economic and social dimensions, pointing to concepts like the ‘gross national product’ and various happiness indices.

The technical/procedural aspect only turned out eight coded items, thus making it the least articulated part of the ERM. The distribution by teaching discipline is three expressions from Physics/Chemistry educators, three from Biology and two from Geography. Physics/Chemistry educators express teaching about the development and use of technology as an obvious avenue to sustainability considerations. Technological achievements are seen as both a cause of and possible remedy for sustainability concerns. By considering a concrete artefact of technology (or a production process), one can calculate or estimate its toll on natural resources and consider potential changes or alternatives. In the coded data, Physics/Chemistry educators tend to express the functioning of technical artefacts and technological systems as central, whereas those from Biology and Geography focus on processes often, but not always, made possible by technology. Take biotechnology, for example: To get acquainted with gene-splicing, pre-service teachers were required to perform the actual process in the laboratory. The educators expressed this as becoming familiar with a technique or process, a core part of the biology discipline. (Interview with UCM educator, Biology affiliation, Time index 12:14-14:12)

Geography educators covered organic farming processes, posing the question of how to keep the energy and nutrient cycles as closed as possible. The notion of ‘cradle to cradle’ also shows up here – described as a process (more than ‘just’ a concept) – in particular, one of the UC Geography educators said that she conducted a number of lessons that involved analysing supply chains for different foodstuffs. The educator focused on how to perform this analysis, especially how it could be performed in lower secondary schools, thus making it an example of an analytical process through which LSS pupils can learn about sustainability.

Constraints on teaching triggered by other levels of co-determination in the ecologies of teaching disciplines

This section deals with how influences from various levels of co-determination affect what was planned to take place and what actually took place in the case course. Twenty-four items were coded as belonging to this category, two of which were also coded as institutional layer influences, and just three dealt with influences specific to the teaching discipline. Thus, the majority of identifiable level influences impacts all three teaching disciplines included in the study. The influences voiced all point in the 'downward' direction of the scale, from above the discipline level to the levels below.[4]

Starting with influences that in the scale can be said to reside at the society level, one can see that the general 'idea' of sustainability marks the didactic transposition process. This is the noosphere at work. As one educator remarked about why sustainability ended up in the course title: 'It is probably a mix of sustainability being trendy and the fact that many things can be subsumed under sustainability.' (Interview with UCC educator, Geography affiliation, Time index 26:48-26:55.) Former Danish education ministers are referenced as having made plans to have sustainability incorporated as an issue for consideration in all subjects at lower secondary schools. The obligation may not be explicit in all curricular texts, but exists nonetheless.

Another strong societal constraint to developing the interdisciplinary case course was the political and traditional reality by which education is divided into teaching disciplines and understood in terms of long-established disciplinary boundaries. This is particularly evident from the way exams are generally construed in the education system, and specifically in the UC layer. Exams are intended to gauge mono-disciplinary competencies. Credit is not uniformly given for interdisciplinary proficiency:

> *We teach them a lot about interdisciplinarity, but they can never cash in on their interdisciplinary proficiency at any [SIC] of the exams that they are required to take in each of the subjects. The term 'interdisciplinary' is not present […] it is in Geography, but not in Biology and Physics/Chemistry […] we focus on something that is not relevant for the exam, but very much so for teaching.* (ASTE Working Day June 10, 2015. UCC educator, Biology affiliation, Time index 33:53-34:25)

Interdisciplinarity is not allowed to supersede any existing teaching, only add to that which is already there. This gives educators an even greater sense of disciplinary congestion or frustration at not being able to give credit for what they hold central to the case course.

On the seventh level of the scale ('school'), the UC educators expressed that being unable to be jointly present at lessons was a constraint. Quite simply, their scheduling required them to be elsewhere. Finding time to jointly prepare lessons was another problem, for which reason the progression of lessons was much less coherent than the educators would have liked. The details of each educator's lessons were insufficiently communicated to the others, an institutional ailment that

[4] Attempts at influence in the other direction were seen. Typically educators referring to prior successful teaching of a particular subject they believed could fit well into the new course. But these statements never gained any traction in the discourse. These proposed teaching elements might have been used in the actual teaching nevertheless, the data does not cover this, but again, it did not have any impact on the discourse surrounding the case course.

afflicted not only the interdisciplinary case course but also most collaboration between UC educators. For example:

> *This work with the broad issue [of sustainability] and me not knowing exactly what is going on [in the other educators' lessons] is something I have often experienced when sharing a Geography course with a colleague. There I face the same challenge: I know he has had some teaching sessions that I have to make connections to, but I do not know what has taken place. This [situation] is actually quite identical; it does not necessarily couple to different teaching disciplines, but to the fact that I have not been present [in his lessons]*. (Interview with UCC educator, Geography affiliation, Time index 37:10-37:43)

While ASTE had provided plenty of extra institutional support (i.e. relief from other obligations) in the first stages of didactic transposition, this support was lacking when it came to the later steps; see Figure 1. This was a severe constraint overlooked in the institutional setup of the ASTE project. Regardless of the unfavourable conditions experienced by the UC educators, they saw the pre-service teachers become aware of interdisciplinary possibilities, and began incorporating them into assignments in their *mono*-disciplinary courses:

> *As they [the pre-service teachers] said: 'We are going to teach these subjects in lower secondary school. We ourselves may be the eighth-grade teacher with the same class in both biology and physics/chemistry, in which case this is the obvious way to do it.' So the pre-service teachers work much more interdisciplinarily than we do!* (ASTE Working Day, June 10, 2015, Time index 39:36-39:52)

The endeavour to make the course strongly interdisciplinary also influenced teaching through the pedagogical level of didactic co-determination. UC educators expressed the need to temporarily forget the constituent mono-disciplinary curricular items, and made it a habit in their lessons to point out to the pre-service teachers when disciplinary boundaries were crossed. A lengthy discussion took place regarding the pedagogical advantages and disadvantages of presenting the pre-service teachers with examples of sustainability as seen from each of the three teaching disciplines involved. Moreover, a significant part of the discourse around the case course dealt with interdisciplinary teaching as a didactic sleight of hand that might or might not influence learning positively. The classic arguments for the need to understand single disciplines before integrating them were raised, and synergy was only believed possible if the team of educators could avoid repeating pedagogical issues that the teaching disciplines had in common. All of these misgivings were never fully dispelled, and as seen above regarding the 'school' level, the lack of detailed communication between the educators doing the implementation only gave rise to continued doubts about the benefits that pre-service teachers could reap from the attempt to teach sustainability in the given interdisciplinary and institutional setup.

How the interdisciplinary setup influenced teaching of the case course

The data revealed 35 instances that could be coded as expressions of influence across the three teaching disciplines. To report them concisely, one can group them into three non-disjoint collections described as follows: A) Attempts (conscious or not) to drag the course in certain directions, B) discrepancies and similarities (real or imagined) in the view on course elements and C) effects of one educator's lessons on another's. These three collections will be elaborated below:

Collection A: Physics/Chemistry educators fought to keep energy issues in the course (once they were there), both as part of the course title and in the course implementation, expressing a wish for a 'flow of energy' component in the course, preferably connected with the notion of 'cycles'. Geography educators often advocated focusing on the environmental dimension of sustainability, which despite regular references to the other two classic dimensions of sustainability, was regarded as more fundamental:

> *You can say that environmental sustainability fits the Geography discipline best, but I always mention the others [economic and social sustainability], so they are included. I strongly stress that the concept is tripartite in its basic form. But you can well argue that if you exploit natural resources and destroy the natural basis you are given, considering the 'worst case' and all, then you would be hard put to maintain the other two… it can be difficult to act in economically and socially sustainable ways if you have a problem in the first place.* (Interview with UCM educator, Geography affiliation, Time index 9:22-10:04)

The view that environmental sustainability was somewhat more fundamental was to a large extent mirrored by the Biology educators. However, they wanted to put greater emphasis on social aspects, or to go more deeply into how specific animals or plants contributed to sustainable processes, leaving the broader overarching implications of sustainability to the Geography teaching discipline.

Educators from one teaching discipline frequently voiced opinions about how another defined sustainability. For example, some expressed that Biology saw sustainability from a species and bio-diversity point of view, while Geography defined sustainability more closely along the lines of human capability to continue production in the long run. Differences in these perceptions of other teaching disciplines lead to a certain amount of, albeit benign, collegial anxiety that misrepresentation might occur. As a Physics/Chemistry educator put it:

> *Now, to ensure that Geography does not lay claim to the only understanding of sustainability, I would like to propose that after Geography has been in charge of this*

> *one day, where the scene is set, then the other teaching disciplines have to come in and present other perspectives on the concept*. (ASTE Sustainability Module Meeting February 2014; UCM educator, Physics/Chemistry affiliation; Time index 57:18-57:40)

Collection B: The preceding quote already shows some disciplinary disparity, but another example directly affecting the pre-service teachers was the Geography stance that organic production differs from sustainable production – an assertion upheld by those from Biology. As the UCM educator remarked:

> *I chose to focus on organic modes of production, more or less equating this with sustainable production, until there was, if not an outcry, then a profound scepticism among the pre-service teachers based on the lessons they had been given by [the Geography educator]*. (Interview with UCM educator, Biology affiliation, Part 2, Time Index 5:06-5:28)

Geography educators perceived sustainability as too great a debate issue to be favoured by those from Physics/Chemistry, and felt that Biology educators would downplay the social and economic dimensions. These conceptions were only partially true, but nevertheless contributed to establishing some rough divisions regarding what each of the educators, and therefore teaching disciplines, were supposed to deal with in their respective lessons. Physics/Chemistry was collectively believed to deal with nutrient cycles, energy flow and experiments verifying the nutrient content of selected foodstuffs. Geography educators were tasked with disseminating many of the general conceptual considerations, and Biology educators would go into more detail about agricultural and animal production. The UC educators did, in fact, cover these elements in their respective lessons, but the interviews and the observed lessons reveal that the educators spoke about, and conducted, the teaching of sustainability in a more nuanced fashion than any of them thought the others capable of.

Collection C: What remains of identifiable interaction when the educators involved all tried to downplay disciplinary individuality? First of all, it could be seen as a sign of interdisciplinary success that rather few instances of disciplinary contagion were visible to the UC educators, but they did not feel that way, tending to believe that the lack of clear references to other lessons was, in fact, due to scarce cross-fertilization between the teaching disciplines. It cannot be verified from the obtained data if one or the other is true. The disciplinary interactions noted by the educators in class were general references among the three teaching disciplines. Physics/Chemistry educators saw Geography being mentioned in connection with groundwater procurement and the nitrogen cycle. Biology was mentioned in relation to photosynthesis and cultivation practices, while the calculation of sugar content was named as a Physics/Chemistry activity (Interview with UCM educator, Physics/Chemistry affiliation, Time index 33:24-35:18; Interview with UCC educator, Geography affiliation, Time index 34:43-37:10; Interview with UCC educator, Physics/Chemistry affiliation, Time index 40:15-41:47).

How considerations of the LSS and university layers influenced teaching of the case course

Forty references in the data were coded as having a bearing on adjacent institutional layers. The LSS layer was mentioned in 21, while 19 related to university.

Close consideration of LSS conditions is a common practice at the UC institutions, not just in connection with the ASTE project. The coded references testify to a number of ways in which influences from the scale levels (mostly the 'school' and 'discipline' levels) of the LSS layer affected the planning and teaching of the case course (lower scale levels of the UC layer). The UC educators closely considered how sustainability was taught in LSS, painting a picture of sustainability as a topic that tends to be somewhat overlooked, and as likely to become a 'tragedy of the commons' (Interview with UCM educator, Biology affiliation, Time index 1:46-2:15; Interview with UCM educator, Geography affiliation, Time index 2:13-3:34). UC educators emphasized taking stock of how sustainability presented itself in LSS curricula, noting how it was often normatively described and clearly referred to the idea of pupils becoming 'action competent'(Mogensen & Schnack, 2010). These considerations directly influenced the lessons undertaken with the pre-service teachers (Interview with UCC educator, Geography affiliation, Time index 38:19-40:34). The considerations also influenced several of the exercises included in the coursework, which were exemplary, meaning they could in principle be carried out with pupils in LSS (Interview with UCM educator, Biology affiliations, Time index 14:12-16:50; Interview with UCC educator, Physics/Chemistry affiliation, Time Index 37:29-38:36; Interview with UCM educator, Geography affiliation, Part 2, Time index 1:50-3:23). Pre-service teachers were to acquaint themselves with how LSS textbooks deal with sustainability. They were to conduct interviews with LSS pupils or analyse texts pupils had written in order to gauge the knowledge expressed regarding sustainability issues. Yet, other ideas were abandoned because the pace of planning at LSS differed from the pace at the UCs. The proposals regarded cooperation that would disrupt the already laid annual class plans. For example, a one-day sustainability event (to be planned and carried out by the pre-service teachers) was proposed, but it was difficult to determine when it should take place and how to garner the support and involvement of LSS teachers in all three subjects (ASTE Three-disciplinary course meeting, November 21, 2014, Time index 1:05:00-1:13:00).

Cooperation with the university layer was a much considered, but troublesome issue concerning the case course. A number of perceptions and experiences were expressed by the UC educators to have constrained efforts to include the university layer to a large degree. The most tangible obstacle was that institutional and labour market conditions prevent university lecturers from teaching pre-service teachers on an equal footing with UC educators. Furthermore, many voiced concerns regarding the ability and knowledge of university partners: The (substantiated) perception among UC educators was that few university researchers had the necessary insight into the LSS teaching profession or UC education. Differences in the didactic approach of people from 'pure' science was also seen as a hindrance to fruitful involvement. The highly specialized knowledge predominant in the university layer was seen as difficult to utilize in the more generalized environment of the teacher education (ASTE Three-disciplinary course meeting, November 21, 2014 Time index 1:19:00-1:27:00; UCM Internal meeting March 12th 2015, Time index 1:18:23-1:25:27).

A more positive effect of educators' constant search for niches in which to insert a university perspective was an increased use of research papers. It became more legitimate for UC educators to point pre-service teachers to such texts, and expect them to be able to handle studying them. According to the UCC educators, this prompted a greater than usual number of pre-service teachers to seek out and utilize research findings in parts of the course that were set up as semi-independent project work (ASTE working day, June 10, 2015, Time index 58:15-59:21; Interview with UCC educator, Physics/Chemistry affiliation, Time index 44:41-45:58). Another reason given for this desirable effect was the pre-service teachers' exposure to the university layer through guest lectures and visits to university-based research and teaching environments, both generally in the ASTE project and specifically in the case course (Startup meeting UCM ASTE interdisciplinary courses, Time index 31:17-32:16).

Concluding remarks

To sum up the findings in light of the two-part research question, a number of general trends can be discerned from the analysis.

With regard to the first part of the research question, the differences bound to teaching disciplines in UC educators' perspectives on sustainability were not overwhelming. On the contrary, the data shows how educators from each teaching discipline advocated a nuanced view, often to a greater extent than they believed each other capable of. The axiological and conceptual aspects of teaching sustainability issues were identified as central to all subject disciplines, albeit the axiological aspect seemed to require closer connection to the other aspects when addressed in the Physics/Chemistry discipline. The technological/ procedural aspect featured less prominently in the discourse of educators from all disciplines.

Along the traditional environmental, social and economic dimensions of sustainability, the educators all felt most at home in the environmental, but worked hard to put the other two on an equal par. The environmental preference is no surprise, as only science disciplines are involved. This only underlines the necessity of the three ERM aspects, which, unlike the dimensions, provide the necessary detachment from the science disciplines.

The shared perspective on the teaching of sustainability relative to the reference model does not mean there were not different disciplinary topics, subsumed under sustainability, which each UC educator pursued with greater zeal, but this was more greatly due to the upper levels of co-determination than to fundamental disciplinary differences in the outlook on sustainability in itself.

With respect to the second part of the research question, when one traces the effects that institutional layers, teaching disciplines and levels of co-determination have on the creation and implementation of the case course, a complex, non-linear picture emerges. The wide variety of influences determining how the course was composed and implemented makes any attempt at a clear-cut conclusion seem like an oversimplification. However, a few trends should be highlighted here: The *institutional layers* adjacent to the UC layer clearly influenced several steps in the transposition process. Notably, knowledge of the university layer served as subtle inspiration for the UC educators during the development process, while more substantial cross-fertilization with the university layer remained problematic and failed to be attained during implementation. The LSS layer, on the other hand, featured prominently when it came to the detailed planning and execution of the course, because the UC educators felt an implicit, but strong obligation to heed the LSS curriculum and the teaching profession in general.

The distinct features of the *teaching disciplines* and, in particular, the opinions UC educators from one discipline held of the others were the source of much debate and had the potential of turning into interesting lessons in which disciplinary distinctions could be pitted against each other and thus enrich the learning of the pre-service teachers. This was evident in the development phase, but never came to fruition during the course implementation because of the constraints endemic to teacher education: The upper *levels* of the ecologies in which the course was embedded shaped the curricular items each teaching discipline could bring to the interdisciplinary collaboration. Indeed, the entire institutional tradition of thinking education in terms of teaching disciplines kept the UC educators in a limbo where they could not, and might not want to, abandon disciplinary distinctions. Trying to cater for their ‘own’ teaching discipline while also connecting with the others left them suspended between positions that seem mutually unobtainable. Sustainability succeeded in uniting the teaching disciplines in this case of interdisciplinary science teacher education, but it appears that the institutionalised disciplinary structure in the context of this case will have to be deconstructed and made anew if the interdisciplinary potential is to be realised.

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Lesson study in pre-service mathematics teacher education: Didactic and paradidactic technology in the post lesson reflection.

Abstract This paper presents a detailed analysis of the post lesson reflection; carried out in the context of eight cases of lesson study conducted by teams of Danish, lower secondary pre-service teachers and their supervisors. The participants, representing different institutions, were all new to the lesson study format. Never the less it is demonstrated how their interaction shape the development of discourse about mathematical learning. The Anthropological Theory of the Didactic is employed as the theoretical approach to analyse the mathematical and primarily didactical praxeologies developed and discussed during the meetings. The study investigates what happens when lesson study, a well-established Japanese "system" for professional teacher development, is transposed to another educational and cultural context, with the aim of enhancing pre-service teacher learning during the practicum of a teacher education program. The findings highlight significant different positions in the discourse during the post lesson reflection. Specific practice-related knowledge is developed, to the benefit of pre-service teachers, educators and researchers alike. This kind of knowledge is of interest and concern to the whole profession of mathematics teachers and the analysis adds to our insight into the potential of lesson study in pre-service education as a meeting place where pertinent actors contribute to the expansion and dissemination of shared professional knowledge.

Introduction and research question

The study of how teachers learn from practice, and subsequently develop their practice, is an ongoing interest of educational research. Many pre-service teacher education programmes seek to build foundations for lifelong development of the teachers' own practice, and in some institutions, this is followed up by induction programmes in the first years of the teachers' career (Howe, 2006). Indeed, it is an important challenge of all teacher education programmes, to facilitate pre-service teachers' first meetings with teaching practice. This paper deals with issues related to the first formalised encounter with the field of live teaching, the so called *practicum*. I investigate an experimental setting for the first practicum period in Danish mathematics teacher education, as it was reorganised based on elements from the Japanese format of lesson study. In order to gain insight into the generation of shared teacher knowledge, I focus on the post-lesson reflection which is part of the lesson study format. In Japan, lesson study is a common format both in pre-service education (e.g. Elipane, 2012) and in regular teachers' professional development (Fernandez & Yoshida, 2004). Many countries support initiatives which try to import this method or "system" for enhancing the professional education and development of teachers, and the use of lesson study in pre-service education poses some unique challenges. Murata and Pothen (2011) describes how they have implemented lesson study in an American context to make pre-service teachers see the connections between the teaching and the learning of pupils. McMahon and Hines (2008) reports how these connections are easily overlooked as pre-service teachers often focus on the technical aspects of implementing their lessons. Moreover, meaningful discussions and support of knowledgeable advisors have been identified by Fernández (2010) as crucial elements of lesson study in pre-service education . In the Danish experiment studied here, none of the cooperating teachers or pre-service teachers involved had any prior experience with lesson study, which makes the reported findings of interest to all who seek to incorporate lesson study in educational and cultural settings where it is not yet an established practice. Lesson study is, very roughly put, a process in which a lesson is planned by a team of teachers or pre-service teachers, and then taught by a member of the team while observed by a number of other people and the rest of the planning team. This larger group then reflects on what happened, based on specific questions and hypotheses developed in the planning phase. This leads to the overall research question: *When the lesson study format is unfamiliar to the participants, what characterize the post-lesson discussion?* This research question will be sharpened in the subsequent sections, but first I need to present the background for this study, relating it to the research literature on teacher education practicum and lesson study. Then I give a brief account of one of the eight cases, which I shall use as a paradigmatic case throughout the paper to exemplify both the presented theoretical model, and then in the findings section, to compare and contrast it with the other seven cases observed. The anthropological theory of the didactic is introduced to model and analyse the research question, before I finally present the methods and findings of the study.

Background

Pre-service teacher practicum is generally portrayed as having an enormous influence on teacher education as a whole (Bergsten et al., 2009) and on pre-service teachers' opinion of mathematics in itself, and as a teaching discipline (Grootenboer, 2006). Much of the research on practicum experience focus on the notion of reflectivity, that is, in order to learn from things done, the learner has to reflect on what has been experienced in practice (see, for instance, Ghaye, 2010; York-Barr, Sommers, Ghere, & Montie, 2005 for numerous references).

The settings for doing, facilitating and promoting these reflections are many: Keeping individual diaries, video recording in classrooms, collective supervision, interviews and lesson study. A main point for pre-service teachers and educators is to set aside time for individual and collective reflection on the practical experience. To develop *shared* knowledge of general interest to the mathematics teacher profession, special attention is naturally given to settings where the parties can meet and reflect *collectively* on the practices of teaching they seek to improve. In pre-service teacher education a number of formats exist where the pre-service teacher meets other persons who are knowledgeable of the profession. The post-lesson interview, where the pre-service teacher and a cooperating teacher meet to discuss issues arising from recently carried out lessons, is a common format that can be both directed and prescriptive, but also reflective and theoretical (Chaliès, Ria, Bertone, Trohel, & Durand, 2004, p. 766). These interviews may take place immediately after lessons taught by the pre-service teacher or they can be postponed, e.g. with a recording of the lesson available for later review. Delayed interview is sometimes reported to improve the quality of pre-service teacher reflection (Watson & Williams, 2004). Another common tool to improve the reflection, and thus the learning and development of professional knowledge, is to include other "experts" in the group of people who join in reflecting on a particular lesson. A Scandinavian example of this is the so called "tripartite conversation", where the pre-service teacher and cooperating teacher is joined by the pre-service teacher's professor from the University College (hereafter abbreviated UC)[1] (Gloppen, 2013; J. Rasmussen, 2007).

An even wider group of people is involved in the joint reflecting on a lesson just observed within the Japanese format of Lesson Study, the setting I focus on in this paper. Lesson Study is a diverse phenomenon and can be seen to involve many distinct aspects (C. Fernandez & Yoshida, 2004). More specifically in this paper, I focus on one important element of Lesson Study: the post lesson reflection. This meeting, focused on collective reflection, is termed "*hanseikai*" in Japanese (see e.g. Peterson, 2005, pp. 71-72 for a short description).

Lewis, Perry, and Murata (2006) identified three critical needs for research on the functions of lesson study: A need to expand the descriptive knowledge base, a need to explicate the innovation mechanism and a need to do design-based research cycles. This paper aims to contribute to the first two needs. Regarding the first, I describe a lesson study experiment situated in special circumstances and I focus on the discourse observed during *hanseikai*. With regard to the second need, Lewis et al. (2006, p. 5) conjectured that: Lesson Study strengthens three pathways to

[1] University Colleges are the institutions in charge of pre-service teacher education programmes in Denmark (for primary and lower secondary school).

instructional improvement: Teachers' knowledge, teachers' commitment and community, and learning resources. I will analyze eight instances of *hanseikai* for evidence of these pathways, as they are expressed through shared discourse about a commonly observed lesson. This shared discourse of *hanseikai* has been described by Miyakawa and Winsløw (2013), as "expressed knowledge and logic behind didactic techniques" (i.e., didactic technology, cf. theoretical section below).

Context and description of the example case

The eight cases of lesson study took place in 2012 and 2013. I will refer to them as LS1 to LS8 and the research lessons were held in grades 8,6,7,8,3,6,5 and 5 respectively. Each instance was centered on one 45 minute lesson, planed collectively by groups of 2-4 lower secondary pre-service teachers, who attended regular teacher education at one of two different UCs. The teacher education program consists mostly of coursework, but with 24 weeks of practicum spread over the programs total duration of four years. The practicum took place at schools affiliated with the UC, and the school follows certain guidelines set together with the UC, to regulate the pre-service teachers' rights and obligations when in practicum. The depth of the cooperation (formal or otherwise) between UCs and schools varies, and depends much on the individual choices of the UC professor and cooperating school teacher. The cooperating school teacher is usually the main interlocutor of the pre-service teachers during practicum. The eight cases took place during the pre-service teachers' practicum period, in their second year, on the initiative of mainly the UC professors. The pre-service teachers were obliged to participate as part of their training, whereas the cooperating school teachers, UC professors and "knowledgeable others" i.e. resource persons from an associated university participated on a semi-voluntary basis. Pre-service teachers in their second year are still somewhat inexperienced and have two more years to familiarise themselves with two other disciplines besides mathematics, which is the only teaching discipline they study during the first two years.

The plan for each research lesson was generated by the groups themselves with guidance from the UC professor and the cooperating school teacher. The lesson plans were to be quite elaborate in order to make them helpful to all participants, including those who would only participate in observation and reflection on the research lesson. While it is common practice in Japan to prepare lesson plans which are readily understandable to persons not involved in the planning itself, this is generally not the case in the practice of Danish teachers or pre-service teachers. To compensate for this fact and for the unfamiliarity with lesson study in general, a brief guide and lesson plan template (See appendix, Table 1 and Table 2) were developed and made available to those taking part in the lesson study. The pre-service teachers also attended a two hour lecture on the nature of lesson study, given by an outside expert, but otherwise no common preparation was given. Therefore the eight cases can be regarded as a pilot study to shed light on what can be accomplished with a minimal implementation of preparation.

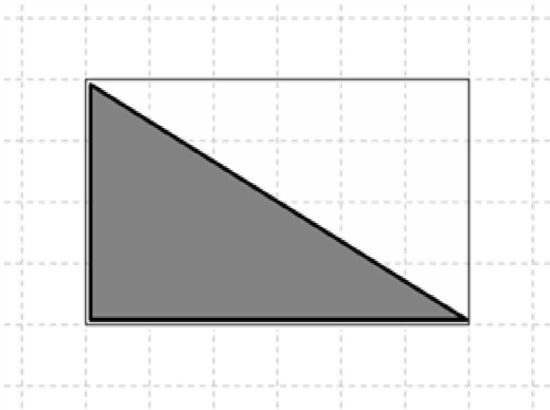

Figure 1: Picture shown to pupils, indicating a way to find the area of a rectangle by superimposing it on a net of unity squares. A triangle is placed suggestively inside the rectangle, alluding a way to derive the triangle area formula from the rectangle area formula.

In order to broaden the context and introduce the theoretical model, I now describe the plan and content of LS8, which will be used as a recurring example. LS8 was chosen because it clearly exemplified issues common to all cases, but other cases could also have been used. The goal for the pupils in the fifth grade class was to develop a formula for the area of right angled triangles. They were to do that by experimenting with the geoboard[2]. First the pre-service teacher presented the agenda for the lesson and then recalled earlier work the class had done on the area of rectangles. This was done as a "teacher led" dialogue. Then the pre-service teacher led a whole class discussion about what right angled triangles are; the discussion was supported by a PowerPoint, displaying right angled triangles in different shapes, sizes, colour and orientation (see also Fig. 2 below). Next a "problem" was introduced where the pupils were to make a number of right angled triangles on the geoboard. The produced triangles were "recorded" by the pupils by copying them onto paper prepared with unity squares. The overall task was to find a "rule" that expressed how to *calculate* the area. A way to find the area of rectangles by counting the squares inside, and also a relation to triangles, were subtly indicated in a figure from the problem presentation (Figure 1). The pupils

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[2] The GeoBoard is a physical board with a certain number of pegs placed in a grid, around which rubber bands can be wrapped to form plane geometrical shapes.

worked on the problem in pairs, and finally their different solutions were discussed and contrasted to each other in yet another whole class discussion.

Theoretical model and analytical strategy

The Anthropological Theory of the Didactic (hereafter ATD) employs an epistemological and institutional approach to analyse "didactic phenomena" i.e. instances of teaching and learning (Bosch, Chevallard, & Gascón, 2006). Didactic phenomena are conceived and given meaning by the institutional context in which they appear. These phenomena are considered as more or less contingent, no matter how "natural" or "eternal" they may seem. Indeed it is the obligation of the epistemologist to question the perceived obviousness of the world as it is presented by individuals or organisations. Below I explain how ATD models all human activity, in particular those of a didactical and mathematical nature, as *praxeologies*. Praxeologies consist of tasks, techniques, technologies and theories, all related to another.

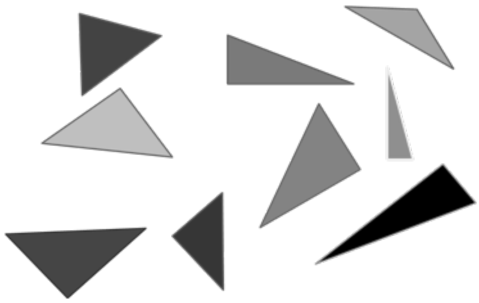

Figure 1: Picture accompanying the specific task (t_1) of finding the right angled triangles among this collection of triangles

Tasks in ATD are understood very broadly, but may be explicitly stated by someone, e.g. when the pre-service teacher in LS8 asks the pupils: "Which of these shapes are right triangles?" The pupils are thus given a task (Denoted by t_1). Generally tasks are something humans are faced with as part of life. They need not be stated by anyone nor consciously recognised as such, even though that is usually the case in school contexts. The response to a task is achieved through the use of techniques to cope with the task. In the example from LS8, a technique may be for the pupil to grab the protractor, place it correctly on the largest angle, read of the scale and conclude whether the triangle has a right angle or not. This amount to a technique τ_1 for the type of task T_1: determine whether a given triangle is right angled. The pair of *type of task* and *technique* (T_1,τ_1) co-define each other, and is referred to as *praxis*. It involves some "doing", physical or mental, which might be more or less mechanical, that is, without considering how the task is recognised, why the task is relevant in the situation, why the technique is appropriate, how or why the technique produces a valid answer etc. It is then obvious, that this pair of task type and technique can never truly exist alone, there has to be some discourse or reasoning regarding the technique, at least some consideration of how to recognize a task to which the technique applies. This explicit consideration of task and technique is called *technology* (often denoted by θ) meaning “techne-logos” or “the discourse on the technique”[3]. Technology may, or may not, be deliberately produced, but it is always present along with human praxis. Proposing an example from LS8, a pupil may be able to tell her seatmate how to use the protractor, and that colour is irrelevant. Her seatmate may confess that she is uncertain whether only triangles with a 90 degree vertex pointing to the right side may be called a right triangle. Such deliberations are observable technology. According to Durand-Guerrier et al. (2010): “... it is an important characteristic of human activity to allow for coherent discourse about tasks and techniques (called technology), and in some cases to organize these discourses in theories that make explicit the understandings and justifications underlying technology and techniques. For instance, an instruction on how to perform a multiplication [of] integers belongs to a technology, while the systematic discussion of why the multiplication methods works is within the domain of theoretical discourse.”(Durand-Guerrier et al., 2010, p. 4)

This quote also introduces the last component of a praxeology, namely the *theory* (often denoted by Θ), which elaborates the meaning of discourse to encompass the whole network of understandings and justifications which are used to account for technology itself and its relation to other technologies. It is a perhaps trivial consequence that accounting for the technology and theory of pupils in regard to a given task can be quite extensive. Nevertheless short suggestive statements may be identified as crucial elements of a theory, e.g. in LS8, the theory of right angled triangles may encompass a clear definition which helps to distinguish these shapes from other triangles.

Discourse in the hanseikai and the sharpened research question

What is discussed in the hanseikai is *didactic* praxeologies (Bosch & Gascón, 2002). Didactic praxeologies can be related to the mathematical praxeologies as they begin with tasks for the mathematics *teacher*, or as in this paper, the pre-service teacher. The generic didactic task is to support pupil’s learning of a mathematical praxeology. For instance, in LS8 the teacher notices pupils’ diverse and imprecise language, which makes it difficult for the whole class to participate in

[3] It is crucial not to confuse the ATD meaning of technology with the every day sense of the word

a common discussion. Clarifying pupils' discourse becomes a task for the pre-service teacher. She reformulates pupils' assertions and draws illustrations on the blackboard to clarify the meaning. These techniques can be used in relation to teaching different praxeologies, but its specific use depends on the mathematical praxeology to be learned as well as other aspects of the situation.

Teachers' didactic technology and theory is more difficult to extract from classroom observation. But my analytical strategy (Andersen, 2003) is that this will be visible during the *hanseikai* phase of lesson study.

Besides the notion of praxeologies, I need two other theoretical constructs from ATD. The *didactic infrastructure*(Chevallard, 2009) and the *paradidactic infrastructure*(Miyakawa & Winsløw, 2013; Winsløw, 2011b). (See Fig. 3)

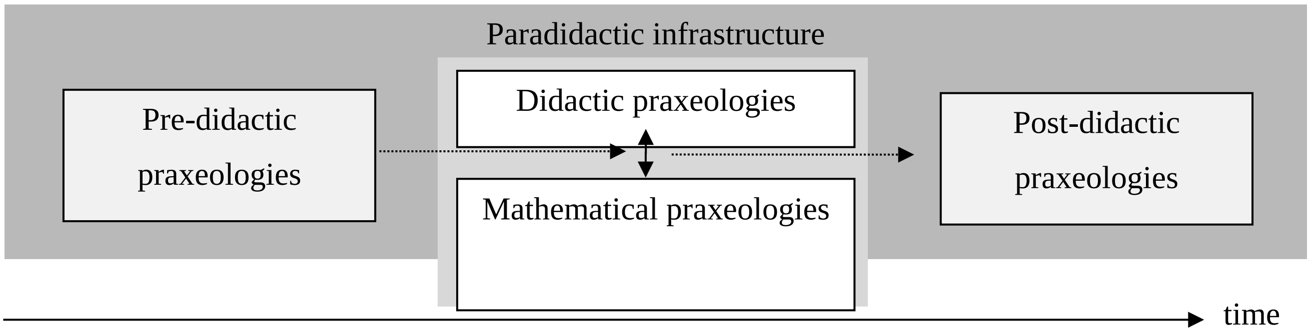

Figure 3: Didactic and paradidactic infrastructure conditioning teachers development of practice and knowledge inside and outside teaching situations. The lesson study format is a form of paradidactic infrastructure, an in particular "hanseikai" is a collection of post-didactic praxeologies. (Model adapted from Miyakawa & Winsløw, 2013, p. 189)

The didactic infrastructure consists of all conditions for the teacher's work when teaching. The physical classroom, for example, is itself part of the didactic infrastructure, as is the duration of lessons, syllabi and overall pedagogical principles of the school. As mentioned above, lesson study holds the promise to enhance instruction by improving upon teaching resources. I here take teaching resources to be part of the didactic infrastructure which either limits, or helps the teacher in teaching situations. The didactic infrastructure conditions the possible didactic praxeologies, which again condition the mathematical praxeologies actually realised in teaching situations. Didactic and mathematical praxeologies are *co-determined*, meaning they influence each other and they are influenced by institutional *levels* outside the school. (For a more in depth explanation of co-determination, see Chevallard, 2004)

Not all teacher work takes place in teaching situations; preparation and professional development are good examples. Everything which conditions teacher work outside teaching situations is part of the *paradidactic infrastructure*. The lesson study process is a paradidactic infrastructure, as it provides a set of conditions under which teachers, or as in this paper, pre-service teachers, has the opportunity to plan and reflect on a commonly observed lesson. The paradidactic infrastructure of lesson study can be further specified to condition *pre-didactic* praxeologies employed before the teaching activity and *post-didactic* praxeologies after.(Miyakawa & Winsløw, 2013, pp. 189-190)

I am now in position to reformulate the research question precisely using ATD: *Which post-didactic praxeologies arises in the unfamiliar paradidactic infrastructure of hanseikai; and which didactic praxeologies are elaborated and developed during the hanseikai?*

Methodology and the collection of data

This paper focuses on the hanseikai, but as this is intimately connected to the planning and observation of the lesson itself, data were obtained from a variety of sources: Field notes were taken during the research lessons and during the hanseikais. I attended these as a non-participating observer except in LS6 and LS8 where I substituted in the role of university resource person (c.f. context section above). The eight hanseikais were audio recorded, and these recordings comprise the main data source for the analysis. In addition the following background material was collected: Materials created by the pre-service teachers for use in the lessons, e.g. presentations, worksheets etc., and of course the lesson plans.

The audio recordings were time indexed, and inventoried minute by minute to produce an initial overview of issues debated. This resulted in a large number of coherent passages which were given a short description, or memo, to characterize the content. Then two types of data review were undertaken: One where the passages were grouped into those concerning the same content e.g. didactic tasks, mathematical tasks, didactic infrastructures etc. And one where the passages were grouped according to the way, and tone, in which the utterances were made e.g. as questions, appraisal, rebukes etc. The first shed light on the developed didactic praxeologies, whereas the latter illuminated the post didactic praxeologies. This time consuming, iterative process entailed numerous re-listening of the audio material, especially as the discourse tended to be fragmented, with one statement referring to another several minutes before, and also when a multitude of discourse trajectories was pursued at the same time. This methodology is inspired by grounded theory (see e.g. Glaser & Strauss, 2009) in as much as no didactic or post-didactic praxeology were hypothesised beforehand, and the process involved successive rewriting of “memos” on what described the above mentioned groupings of data. ATD does not describe or recommend any particular method be used in the gathering or structuring of data, it provides the analytical unit (i.e. praxeologies), and as a consequence it was inevitable that the described method would end in findings that could be described in these same terms. This is not the case for research based on pure grounded theory. ATD holds that praxeologies are institutionally situated; therefore it is pertinent to look for differences and similarities in discourse according to institutional categories. In this way ATD guides one in data analysis. In order to present this in a clear way, characteristic quotations from the groups of audio recordings has been selected for presentation in the findings (Section 0), The quotations, marked with LS1 to LS8 from which they belong, and the pertinent time index, was transcribed and then translated from Danish by the author.

Findings

Following the sharpened research question, I first present the post-didcatic praxeologies observed in the hanseikai phase (section 0). Then I take a closer look at the didactic praxeologies that turned out to be discussed in the hanseikai (section 0).

Post didactic technology in the paradidactic infrastructure of hanseikai

Let me recapitulate the need to expand the descriptive knowledge base regarding lesson study. When you try to transpose an element of paradidactic infrastructure, a number of things happen that you are unable to anticipate based on praxeologies commonly found in the institutional setting which gave birth to this element in the first place. What is seen as a natural and therefore unquestioned convention might turn out to be a vital characteristic of the successful functioning of the element. Therefore by trying to adapt lesson study to a new institutional context, something can be learned which expands our knowledge of the “original” lesson study format. One first realisation is that lesson study, as the “invading” paradidactic infrastructure will be entwined with existing infrastructure, the consequences which will be shown below. The overall paradidactic task type (T_1) facing the participants of the hanseikai, is to make comments regarding the lesson just seen. (T_1: Express useful observations related to the lesson plan, lesson observed, and questions for discussion posed by the pre-service teachers) Several techniques can be employed in this endeavor, which I will not elaborate on, but instead jump straight to looking at five post-didactic *technologies* related to T_1, which featured prominently in the hanseikai. The first I could term “performance evaluation”.

Evaluating the personal performance of the executive pre-service teacher ($\theta_{1,1}$)

As mentioned above, nearly the only formal introduction to the new paradidactic infrastructure was the brief guide on lesson study written by a university researcher participating in the experiment. This document now needs further commentary. It is made up of three pages of description (table 1 in the appendix) in addition to a one-page expandable standard form in which to fill in the lesson plan. The standard form consists of two sections (See Table 2 in the appendix): One to give the gist of the lesson, and one to specify the temporal progression of the lesson. Looking first at the description, I summarise the proposed characteristics: 1) Lesson study is described as a repeatable process of planning, observing and reflecting, in which the participating pre-service teachers and cooperating teachers refine a lesson plan. 2) One of these cycles has a special observation and reflection session to which a wider audience is invited, which gives this part of the lesson study process some likeliness to the "open lesson"-format (Miyakawa & Winsløw, 2013). 3) It is emphasized that in 2) the discussion must be centered on concrete observations of the lesson, primarily formulated as questions, never as critique of the executive pre-service teacher. This last recommendation resonates well with the ubiquitous quality of all descriptions of Lesson Study in Japanese institutional settings: "a critical factor is that the *lesson* be criticized, not the teacher"(Padilla & Riley, 2003, p. 287, my italics) This point turned out to be difficult to achieve in more than half of the observed instances (LS2,4,5,6,7), especially LS4 exposition very clear examples of this tendency:

> "..., but I thought that; couldn't' you just have told it to them, or set the time longer..." (One pre-service teacher to executive pre-service teacher, LS4, Time index 11:30-11:37)

> "You use a lot of time with certain groups...[others] have raised hands, it is too bad if they should loose momentum... but that said, I think you interact well with the pupils." (One pre-service teacher to executive pre-service teacher, LS4, Time index 13:40-14:08)

> "Could we try to direct our comments more towards pupil learning in what we observed instead of specific comments to each other? (Cooperating UC professor, who moderates the discussion, LS4, time index 14:41-14:51)

The two first quotations are just a few examples of discourse directed at evaluating the *performance* of the pre-service teacher who did the actual teaching of the lesson. The all-pervasive use of "you" in second person singular form gives the impression of a non-collaborative effort behind the lesson. The flow of the lesson and the interaction with the pupils appears as the executive pre-service teacher's personal problem. In the third quote, the moderator of the discussion tries to change track, but the "verbal assault" continues and the executive pre-service teacher is pressed to repeat the moderator's request to focus on pupil learning:

> "But what about the purpose? ... It's just with regard to what [the moderator] said; it [the comments] should be more in connection to that!" (Executive pre-service teacher, LS4, Time index 17:15-17:25)

It is not just the pre-service teachers themselves who use discourse that seek to evaluate personal performance; it is also common among the cooperating school teachers:

> "I'll begin by saying that you connect very well with the children. I can feel this, and they respect you, and they like to ask you about things. If you did not have this, and they did not believe in you, they would not ask. And I think that is very good!" (Cooperating school teacher to executive pre-service teacher, LS5, Time index 10:20-10:35)

Discourse about how the pre-service teacher interacts on a personal level with the pupils (teacher-pupil relation, classroom management, seeing the whole class, giving clear directions) is not just a peculiarity of Danish teachers. Comparing with the work of the "guiding teacher", attached to teachers in their first year of induction in Japan, we see a similar emphasis on "understanding pupils". Japanese guiding teachers regards the communication and relationship between the teacher and the pupils as the most important factor, without which a new teacher will make no progress. (Padilla & Riley, 2003, pp. 284-285)

Challenge and probe pre-didactic and didactic praxeologies of the pre-service teacher team ($\theta_{1,2}$)

This technology is something akin to *exam-like evaluation*, and is especially prevalent among the cooperating UC professors:

> "Now I am going to say something which I did not plan on saying, but I'll say it anyway ... when I read this lesson plan at home, I got no idea about what was going to take place, there were no details at all, so I thought: " They have completely misunderstood everything." (Cooperating UC professor, LS1 36:08-36:27)

Here the UC-teacher clearly perceives that this comment might not be appropriate for the post lesson discussion, but it highlights a (perhaps natural) beginner's difficulties in writing a lesson plan suitable for a lesson study. As mentioned in section 0 it is generally not a common practice of Danish teachers or pre-service teachers to share lesson plans with others outside the team. As a consequence most lesson plans are written in an implicit manner which is not easily accessible to outsiders. Nevertheless, exam-like discourse is common throughout all eight cases, e.g. the following sentence which is nearly ubiquitous at the end of all traditional Danish oral examinations:

> "Is there something you think you haven't had comments to, which you would like, or is there anything else you would like to add? [Long pause]" (Cooperating UC professor to group of pre-service teachers, LS3 51:00-51:09)

This prompting of pre-service teachers to supply answers are a usual element of UC professor talk, putting focus on something the pre-services supposedly should know:

> "But to adhere to what [another UC professor] said, we lack other ways to organise the end of class discussion. Do you have any good suggestions for that? (Cooperating UC professor to group of pre-service teachers, LS6 33:36-33:44)

The exam-like discourse is characterised by appraisal and by directly addressing the pre-service teachers in ways that will make them expose what they know, and perhaps especially reveal the limit of their knowledge.

Desirable avenues of reflection are suggested to the pre-service teacher team ($\theta_{1,3}$)

Exam-like discourse in the hanseikai was often combined with instances of what may be termed "guidance", in which a UC professor attempted to direct the pre-service teachers' attention in certain directions. Something which they should consider in future work or something they should just "think about". Guidance discourse is often linked to specific suggestions about how to handle or change a situation seen in the lesson:

> "...yes, but just try to understand what I am thinking. It is about this: You cannot speak with each single pupil here at the end [of the lesson]. And then it is I am thinking: How can you obtain knowledge about pupils thinking? This is what I want to challenge, and want you to think about. Can we produce some new ways in which to capstone the lesson, where we obtain the knowledge that you are interested in... There is no simple answer, that's not what I'm saying, but that's what I think we should talk about. (Cooperating UC professor, LS6 28:48-29:17)

The guiding discourse is given by UC professors both when solicited by the pre-service teachers and when not, whereas knowledgeable others, mostly from the universities, only did so on explicit request. The role of UC professors as guides for the pre-service teachers are common to all ordinary pre-service teacher education in Denmark, indeed the time allocated to UC professors' direct interaction with pre-service teachers is divided in two categories which are termed in the following way: *Teaching time* with whole classes, and *guidance time* with individual or smaller groups of pre-service teachers. It is understandable that such well-established paradidactic infrastructure will significantly influence the discursive actions taken. Practicum is in itself a paradidactic infrastructure in Denmark, and the demands on what it should support have changed over the years. One current requirement is to provide a "space" for investigations into one's own and others' practice (2011). Practicum is furthermore a component of the study programme which the pre-service teachers have to *pass*, in some kind of examination managed by the cooperating teachers from the school and the UC. The examination focuses on: didactics, classroom management and "relational work". This precipitates the close linkage between $\theta_{1,2}$ and $\theta_{1,3}$.

Concerning didactic praxeologies of a general nature ($\theta_{1,4}$)

There is a tendency, especially among the "knowledgeable others", to frame their comments on the basis of an observed didactic praxeology, and then quickly rephrase it into a general didactic concern, which the observed occurrence is an example of. This can be seen in the following example where the aim of the lesson is to "understand" the multiplication principle in combinatorics:

> "We couldn't care less how many menus can be made of something in some fictitious burger bar. How is it we get the problem to be the problem we actually want to work with? [...] There is a fundamental recurring challenge in everything we do of this kind; we ask concrete questions, but what we really want to work with is something else." (University resource person, LS4 27:57-28.23)

Pointing out general issues can be productive, if the rest of the participants can relate to the shift in abstraction, and the discussion does not turn into detached philosophies of education. Indeed a shift to more general aspects regarding the issues debated has a tendency to bring out the understated institutional understandings, which is particularly clear in the following exchange regarding pupils' use of mathematical terminology:

Pre-service teacher	Of course you put it [the words] in their mouth, you are bound to, since it is not natural for them to use it, but anyway I think…
UC_professor_(interrupting)	Even the fact that they do say it [, is a good thing…]
Pre-service teacher	I think there was several who said it, but it is difficult, it is still very new to them, these here things…
Uni. resource person	I have the desire to ask what it is. What is so good about it? Exactly that they say the word itself?
UC professor (surprised)	They have to acquire the mathematical language, and if they only hear it, then they will be able to recognize it in situations where they hear it. But if they have to learn to use it, then it also requires the teaching to build upon use in class.
Uni. resource person	Yes, I can also see in the lesson plan that you [pre-service teachers] put a lot of emphasis on pupil assertions, that is, like a "sign", that if they use some of the earlier terms, then they are on the right track.

(LS2: Time index 26:40-27:39)

It is clear from the whole exchange that the school and UC institutions tacitly agree on certain assumptions on the value of using mathematical terminology; this often appears as unquestioned didactic *theory*. When they are questioned, a moment of tension arises, and a longer exchange on the general issues of mathematical language takes place. Questions that challenge what is taken for granted in one institutional context can be taken as an annoyance, or an opportunity to reconsider usual didactic praxeologies - particularly at the level of didactic theory. This is definitely a great potential of the lesson study hanseikai.

Concerning the lesson study format ($\theta_{1,5}$)

This last technology is endemic to the experimental nature of the lesson study. Interspersed between talk directly related to the observed didactic praxeologies, we find a discussion regarding lesson plans and hanseikai in general. Firstly the lesson plan template engendered extensive debate in some of the post lesson reflections (LS2, LS3, LS4 and LS5). The nature of a temporally tight lesson was of concern to the pre-service teachers. Some had great difficulties judging how long time each teaching activity would last, making them apologetic in the post lesson discussion:

> "There were some [pupils] who did not have time to finish one task before I gave them the next. Some of them could have used the entire lesson on the first task." (Laughing nervously) (Executive pre-service teacher, LS4 8.36-8.46)

> "I wish that there were more time for them [the pupils] to try measuring triangles put together"…"...but again shortage of time; time-pressure! I had prepared more triangles in order for them the get a deeper understanding, which was not so smart considering the shortage of time." (Executive pre-service teacher, LS5 4:40-4:45 and 32:30-32.41)

This was recognized by the participating resource person, providing yet another example of $\theta_{1,4}$:

> "This discussion illustrates after all, that even though we start from something concrete, we quickly get into more general points of interest to the teacher, a lot of different ones actually. For example this about how to make the "didactic time" work, in order to provide challenge and make it clear where the lesson is heading" (Uni. resource person, LS5 42.10-42:35)

It clearly exposes a general difficulty of many pre-service teachers. They are unaccustomed to making a very precise plan for a single lesson. It is evident that pre-service teachers could benefit from repeated experiences of the same lesson. Having opportunity to make several "test-runs" as recommended in the given lesson study guide would counter this difficulty, and make it less prominent as an object for discussion in the hanseikai. The fact that few pre-service teacher teams had test-run opportunity makes the challenge of didactic time less attributable to the pre-serviceteachers themselves. Meanwhile the other participants in the hanseikai had a more relaxed view of the strictness and merits of trying to estimate how long teaching activities would last:

> "It is difficult to carry out a tight schedule with minutes indicated as you have; they never fit, do they? So I think it is good that you just say: Ok, then I give a little here and take a little there." (Uni. resource person to pre-service teacher team, LS2 14.51-15:04)

> "To me it matters little if you overshoot by two minutes or undershoot by one. I believe the schedule is more a factor while preparing; you really consider deeply what this particular activity contains, and how long you imagine it will take." (UC professor to pre-service teacher team LS2 15:17-15:33)

Other characteristic talk about the lesson study format concerns the hanseikai itself, and this was typically seen in the start or end of the discussion. We see again the clash with the existing post didactic practice of giving guidance to the pre-service teachers, something which the participating UC professors are in fact quite aware of, even if they are prone to lapse back into $\theta_{1,2}$ and $\theta_{1,3}$ themselves, as we have seen above.

> "This conversation is really about the teaching and the learning of the pupils, and not as a usual practicum guidance session about whether Sakin [the executive pre-service teacher] was standing "in the right way" at the blackboard, writing in an ugly fashion or that kind of thing [laughs]" (UC professor LS6: 2:04-2:17)

UC professors give introductory remarks to set the scene for how the hanseikai should proceed and how the post didactic technology should be:

> "When we make comments, focus is on the teaching objectives; that is, to what degree did the [actual] teaching live up to the expectations? [...] and of course, all comments should be phrased constructively, because it is not our role to judge in any way, but to give feedback which the team can use in the rest of their practicum." (UC professor, LS2 4.48-5:27)

Even though the stance of judgement was intended to be minimized, we have seen it occur ($\theta_{1,2}$), and the pre-service teachers were somewhat unsure of the agenda for the post lesson reflection:

> "I have been anxious to know what it was we were going to evaluate, how it was going to take place, because it is really cool to have someone else look at what we are doing; so I think is has been nice, [...] it's not that I imagined that I would be "slaughtered", but I was uncertain how much you would dig into the mathematics and didactics." (Executive pre-service teacher, LS1 56:02-56.50)

It is doubtless that all five described technologies contribute to addressing vital challenges facing the pre-service teacher in practicum, but are they all desirable in lesson study? While feedback on pre-service teachers' personal performance ($\theta_{1,1}$), as well as guidance ($\theta_{1,2}$), may be much desired by the pre-service teachers themselves, there seems to be nothing that warrants the use of speech which alludes to examination ($\theta_{1,3}$). If the aim of lesson study is to assist pre-service teachers become more knowledgeable about didactic praxeologies common to the entire mathematics teacher profession, then the general inquisitive discourse ($\theta_{1,4}$) appears desirable. It is noteworthy that participants from a given type of institution do indeed seem to have prevalence for certain types of discourse. In that respect it is valuable, that the kind of lesson study experimented here brings them all into considering a shared teaching experience, providing a nexus of perspectives that would otherwise not exist.

The five kinds of post didactic technology shows that there are still some way to go before having lesson study in prospective teacher education that revolves closely around lesson plans which try to tackle didactical problems of general concern to the mathematics teacher profession. One of the main reasons for having lesson study in Japanese teacher education is to 'facilitate the transition of prospective mathematics teachers from being students in methods courses into undergoing actual teaching practice in schools' (Elipane, 2012, p. 9). This means Japanese pre-service teachers are to prepare themselves for engaging in lesson study throughout their careers. This is obviously not (yet) a common practice in Danish schools, so what benefits in the short term can be reaped from lesson study in the practicum setting? I propose the ideal to strive for is the ability of pre-service teachers to identify key didactical problems which could otherwise be hidden behind all the personal challenges of becoming a teacher; and to realise that some challenges are faced by everyone in the profession, and that these challenges can be taken up in collaboration between schools, UCs and universities. In the following section I will take a closer look at the praxeologies that emerged from the teaching experiment as general issues for the profession of mathematics teachers.

The technology of didactic praxeologies

It is obvious that a large number of didactic praxeologies were discussed if one looks at all eight cases of lesson study. Every mathematical praxeology that the pre-service teachers sought to help the pupils acquire gave rise to numerous enacted didactic praxeologies, and even more were suggested as alternatives in the hanseikai. With praxeologies being defined by tasks and further differentiated by a multitude of possible techniques, technology and theory, it is impossible here to give a comprehensive account of all eight cases together. Instead I present three didactic praxeologies from LS8, and special emphasis is given to the technology part, which is readily observed during hanseikai. The observations presented were also prominent in the other cases, and can therefore be considered of general importance to pre-service mathematics teachers.

Didactic praxeologies of whole class discussions

It is a mainstay of all the eight observed lessons, that the pre-service teachers engage themselves in a discussion with the whole class after the pupils have worked for some time on a designated mathematical task. That is, the pre-service teachers undertake the didactic task type T_2:

T_2: *Orchestrate a common session of discussion with the class, to top off individual work.*

In a Japanese lesson this type of task would take place in a phase called *neriage* (Shimizu, 1999). In general, numerous techniques can be employed to solve this, depending on the purpose of the common session. In LS8 the specific technique used can be described as follows

τ_2: The p*re-service teacher calls on a pupil from mainly one group to describe in words how they propose to find the area of the triangle and to write it as a formula. Pre-service teacher draws on the blackboard and asks clarifying questions: "Was this what you meant?" etc.*

The common session was discussed during hanseikai, and the discourse can be collected into the following two technologies which relate to pros, cons, alternatives to, or expansions of the chosen technique. Each technology is illustrated by a short citation from the audio recording of the LS8 hanseikai:

$\theta_{2,1}$: *Draw attention to important mathematical points and share these points with the whole class*:

> "I was concerned whether all [pupils] were paying attention during your [summarizing] review, because their minds tend to wander when they have been engaged in [individual] work ... but on the other hand I consider the review to be important; it is very important to get it [the mathematical knowledge]. (UC professor, LS8 25:13-25:32)

$\theta_{2,2}$: *Expounding (only) a finite number of pupils ideas and being selective about them*:

> "There is a suggestion [from a pupil] where you have a right angled triangle, and a line cutting, around which you flip [part of the triangle] ... what are the possibilities in this? It does not fit readily into the progression towards understanding area. ... We skip this

> saying “that was a nice suggestion, does anyone have another” “(University resource person, LS8 26:10-26:34)

The citations naturally express only singular points in the discourse, while the technology stands for the totality of utterances in relation to the technique, which can be collected into the two described technologies. These two technologies express knowledge about how and why the teacher directs the class towards the intended learning goals of the lesson. They elaborate what is regarded as viable and valuable courses of action in the concluding phase of the lesson.

Didactic praxeologies of supporting pupils independent explorative work

All the lessons in the experiment involved a phase where pupils were to investigate some problem, either in groups or individually. In Japanese lessons, this phase is called *kikan-shido*, in which the teacher mainly circulates among the pupils, taking note of their suggested solutions and clarifying the problem if necessary (Stigler & Hiebert, 1999, pp. 79-80). However in the case context, the pre-service teacher tries to help pupils more actively in the problem solving process. This is a common characteristic of such phases in Danish mathematics teaching. In our eight cases of lesson study, this phase covered more than one third of the lesson time, frequently more, and always more than anticipated by the pre-service teachers. The more “open ended” or explorative the problem was, the longer the phase became. The pre-service teachers wanted as many of their pupils as possible to find some solution. They wanted to tailor the instruction to the individual needs of each pupil, or small group of pupils, making the teaching much differentiated (Carlgren, Klette, Mýrdal, Schnack, & Simola, 2006).[4] Therefore a complicated didactic task T_3 was faced by the pre-service teachers in the Danish equivalent of the *kikan-shido*:

T_3: *Actively support individual pupils while they do explorative work.*

The techniques outlined below all take into account the tacit requirement that the support must not give away an answer to the problem, thereby ruining the learning potential of the problem solving situation. Again these techniques can be varied, but in the context of LS8 one example is the following:

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[4] “Differentiated teaching (*undervisningsdifferentiering* in Danish) is a fundamental principle written into the Danish national curriculum, and the principle permeates all teaching and thinking about teaching at primary and secondary level in Denmark.

τ_3: The *pre-service teacher enters into a dialogue with the pupil who is either "stuck" in the problem solving process, or who needs further challenge.*

The quality and nature of this supporting dialogue lends itself well to debate during hanseikai, and the pre-service teachers are most interested in ideas about what good practice could be. The support dialogue in LS8 was successful, so the following excerpts mostly praise the displayed practice:

> "You are really good at posing questions which make them [the pupils] think ... to make them think mathematically, also to make them express themselves mathematically, without you telling them what to say" (ASTE pre-service teacher (specially invited pre-service teacher), LS8 14:30-14.44)

> "I am impressed by today's pre-service teacher's ability to deny pupils direct answers, to let the group themselves decide when an answer is correct. Thereby letting the mathematics be the authority, and not just the teacher saying "this is how it is". " (University resource person, LS8 17.28-17.45)

These utterances are exponents of didactic technology, respectively:

$\theta_{3,1}$: *<u>Use of questions</u> posed to pupils makes them think more deeply, and more mathematically, about the exploration.*

$\theta_{3,2}$: *<u>Denial of direct answers</u> promotes more independent and self-reliant pupils.*

It be could argued that the underlined parts belong to didactic technique, but the articulation in the hanseikai takes them into the realm of didactic technology. (Note also that the cited utterances are examples of the post-didactic technology $\theta_{1,1}$)

Didactic praxeologies of fostering pupils mathematical communication

In section 0 we saw that the development of proper mathematical language among pupils was regarded as important practice by the UC professors, and how tension arose when the importance was questioned. In this section we will take a closer look at the related didactic technology defined by T_4:

T_4: *Support the pupils' development of, and use of, mathematical language.*

A multitude of techniques were used if we look at all cases, but again I focus on LS8. LS8 distinguished itself with respect to this task, because here the pre-service teachers actually wrote down a question closely associated with T_4 as one they wanted to discuss in the hanseikai: “Are mathematical terms used by the pupils while working in pairs on the problem?” (From LS8 lesson plan, pp.3) And this question also featured prominently in the discussion. The technique used to handle T_4 can be expressed as follows:

τ_4: The pre-service teacher should consistently use mathematical terms herself, appreciate pupils mathematical statements, even in colloquial terms, and re-voice these statements using the mathematical terms.

An example of immediate re-voicing can be seen in the following quotation, recounting an exchange between the pre-service teacher and a pupil:

> “Even though the pupil says something about *squares*, then you [the pre-service teacher] are able to put in *rectangles*, asking: “yes, did you say rectangle?” and then pupil respond by: “No, I actually said *square*”“(University resource person, LS8 18.45-18.51)

The didactic technology to justify and explain the technique revolves around the notion of “appreciative communication”, see e.g. (Bae, 2012), which is not specific to mathematics teaching, but deemed specifically useful to help pupils use mathematical language where the exact terms carry more precise meaning. The idea is to appreciate the fact that statements of a mathematical nature is at all put forward. This will in turn lead more pupils to dare enter into communicating about mathematics. And finally the teacher’s consistent use of precise words will make the pupils adopt these.

> “I noticed that many of the mathematical terms and explanations only appear [in pupil communication] when someone comes and asks [them] a question ... your way of speaking to and with the pupils is very appreciative, and this really helps [them feel comfortable using mathematical language] ... e.g. [pupil says:] “we use these pencil-strokes”, and then [pre-service teacher says] “yes, we use these pencil-strokes” (Cooperating school teacher, LS8, 11:02-11:44)

Only later will *pencil-strokes* be re-voiced as *straight lines*.

The lesson progression for pupils to make triangles, first on the geoboard, then on paper and then formulate a rule and write it down was identified as essential. These transitions between representing the triangles and rectangles in different media helps pupils acquire the intended mathematical praxeology:

> “You do something with the rubber band, and then you transfer it to the [paper] and look at it anew. Just like you said, one thing is to find a calculation rule, but in the

> moment you have to write it down, it will be internalized in another fashion. In the same way I think [the change in media] is important to retain. (Observing pre-service teacher, LS8 22:40-22.57)

The importance of identifying subtle quality differences in pupils' mathematical language were also displayed as technology for τ_4:

> "I heard somebody say: "length and width and then we just take half of it", really that is perfect. And there was someone who found the truly perfect: "Multiply length and width and then we divide by two" all by themselves and that was fantastic because this was what we wanted" (Observing pre-service teacher, LS8, 23:00-23:20)

Below is an attempt to phrase all this scattered discourse in one dense technology. This is not easy, but it just reflects the richness of the didactic praxeology developed during the lesson study process in general and in the hanseikai in particular:

θ_4: *Appreciative communication and re-voicing will enhance pupil participation in mathematical discourse and make this more precise. Work in pairs, use of different media in which to represent the mathematical objects and the requirement of a written rule, is conductive of their oral and written mathematical language.*

Conclusion

This paper adds to the descriptive knowledge base of lesson study, c.f. the first need as stated by Lewis et al. (2006) by focussing on the hanseikai phase of lesson study situated in pre-service teacher education. Even though discourse is difficult to capture due to its multifaceted and scattered appearance, this paper shows that the context of hanseikai is remarkably well suited to provide information on the technology of didactic and paradidactic practices. It can be concluded from section 0 that the post-didactic praxeologies of hanseikai compete with existing infrastructures in schools ($\theta_{1.1}$,) and in teacher education ($\theta_{1.2}$ and $\theta_{1.3}$). The inclusion of resource persons from universities is an important dimension of the paradidactic practice of hanseikai ($\theta_{1.4}$), thus explicating part of the innovative mechanism behind lesson study (second need stated by Lewis et al.). With this added dimension, seemingly natural institutional tenets can be questioned, opening up a deeper consideration of these to the benefit of each institutional perspective. The identification and reflection upon points of contention between the institutions is valuable because it works in favour of theorizing praxis and utilizing theory, that is, to strengthen the connections between the praxis part and theory part of mathematical and didactical praxeologies. The result is that different institutional preferences in the discussions are a source of new insight for all participants. This finding corroborate other research into lesson study in prospective teacher education (M. L. Fernandez & Zilliox, 2011; Yu, 2011)

It is furthermore evident that the unfamiliar infrastructure of lesson study in general and hanseikai in particular becomes a prominent object for reflection ($\theta_{1.5}$). Guidelines and preparatory introductions are insufficient to facilitate a clear transition from existing paradidactic infrastructures. This may in hindsight be unsurprising, but it is significant to all who engage in lesson study, that the hanseikai also serves to evaluate and develop the technique and technology of lesson study as a paradidactic practice. The greatest drawback, from the unfamiliar infrastructure and the above mentioned institutional preference, is the lack of a common discursive direction in the hanseikai. This could reasonably be ameliorated by improvements in the prepared lesson plans, but until firm predidactic praxeologies for preparing lesson plans, suitable for lesson study, are established, it may be difficult for pre-service teachers to extract didactic knowledge of pertinence to the teacher profession in general.

Looking at the pathways which Lewis et al. (2006) claims are strengthened by lesson study, it is seen how didactic praxeologies related to mathematics teaching are developed (section 0). In several of the eight hanseikais they tend to be obscured by paradidactic challenges, but they are still there. Three of these were presented in the context of LS8 where they did stand out clearly: How to carry out common sessions which sum up the individual mathematical work (T_2), how to support mathematical exploration (T_3) and how to foster mathematical language (T_4). The praxeologies these tasks engender are connected to teaching that has mathematical problem solving as its focus: Mathematical problems should be explored by the pupils themselves and they must be able to communicate their exploits among each other in a precise manner. The exploration should lead to common understandings shared by the whole class. The hanseikai exhibits discourse, described by the didactic technologies $\theta_{2.1}$, $\theta_{2.2}$, $\theta_{3.1}$, $\theta_{3.2}$ and θ_4, that justifies the techniques employed by the pre-service teacher to resolve the three mentioned tasks. Using the framework of ATD it is demonstrated that didactic technology expounded in the hanseikai provides the pre-service teacher and the participants in general, with mathematics teacher knowledge, which is understandable, accessible and useful due to its grounding in collectively observed teaching practice.

Acknowledgements

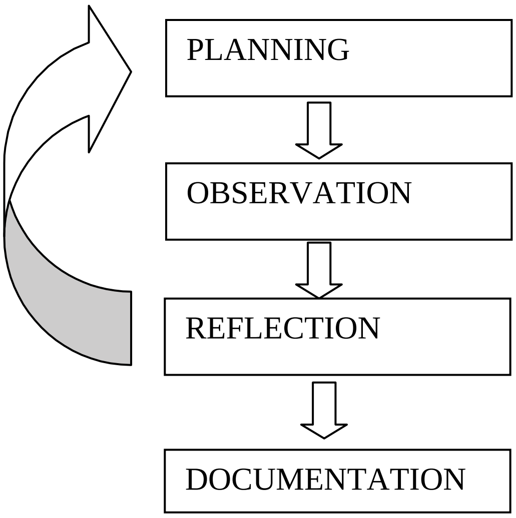
The author would like to acknowledge the Lundbeck Foundation for financial support and Professor Carl Winsløw, the editor and the anonymous reviewers for many useful comments to earlier versions of the paper.

Appendix

Table 1 Translation of guide to lesson study

A SHORT GUIDE TO THE LESSON STUDY PROCESS W.R.T. PRE-SERVICE TEACHERS IN THE ASTE PROJECT

A complete lesson study consists of four phases, of which 1-3 may be repeated several times. This document explains the case where the team planning a lesson is a group of pre-service teachers:



1. PLANNING (Group meetings, individual studies)

Selecting a topic for the lesson (selected from a collection of lessons that corresponds to a chapter in the textbook and/or curriculum)

Study of the textbook, curriculum and possibly existing lesson plans

Formulation of specific objectives for the lesson

Construction of lesson plan (see template)

2. OBSERVATION (in the classroom with pupils)

The lesson is taught by one or more members of the group

The other members participate as observers (taking notes) and other observers also participate, see below.

3. REFLECTION (Group meeting shortly after the lesson)

Submission of concrete observations from the lesson and based on that reflection regarding the connection between goals/questions and observations. (These can form the basis for a review of the lesson plan in a following new phase 1)

4. DOCUMENTATION

This part shall be agreed between pre-service teachers and UC professors(s)

The following are some guidelines for 1.-3. within the framework of teacher education where the lesson is planned and implemented by pre-service teachers under the guidance of an experienced cooperating teacher and one or more UC professors. It is suggested to let an initial test run of lesson, observation and reflection take place in a smaller group - for example, only consisting of cooperating teacher and pre-service teachers (meaning the description of phase 2 and 3 below will only be partly usable). Of course one can only test a lesson once in the same class, so several passes of phase 2 and 3 will require several parallel classes which can meaningfully be subjected to the lesson.

1. PLANNING

In cooperation with UC professor and cooperating teacher: Select a specific topic from the school discipline. The topic can be wide or narrow but should preferably contain some special challenges for pupils, and thus the pre-service teacher.

Formulate these challenges, more precisely, supported by a detailed study of what curricula, textbooks and literature (e.g. from the course work or from own search) says about them.

Select a small number (2-3) of these specific challenges which the lesson should help the pupils with.

Design a *problem* (e.g. an open task) that the lesson is to introduce to the pupilss and at the same time

is sufficiently rich, so the solution will involve overcoming the selected challenges and

is designed so that pupils have resources to provide at least partial solutions - and preferably with different approaches appropriate for the pupils

This is a very central part of the lesson so you should take the time to fine tune the problem!

Plan the lesson in detail using the lesson plan template. Note that the lesson plan must be useable as a tool for observation and therefore should contain explicit, comprehensible hypotheses and questions that observers can focus on - and which mainly relates to the illumination of pupil learning.

Lesson plan will be discussed at length in the team internally as well as with the cooperating teacher and UC professor - if possible on several joint meetings before the first observation.

2. OBSERVATION

The event takes place in a regular classroom, where pupils participate in the lesson carried out by <u>one</u> pre-service teacher. The observation is usually attended by representatives from various stakeholders in teacher education and practicum school, including at least persons 1-5 below:

1. A group of pre-service teachers who have planned the lesson together, and one of which conducts the lesson in the role of teacher. Unless otherwise agreed, it is only the latter that communicate with pupils in the lesson

2. A cooperating teacher who is the regular class teacher and who guides the group of pre-service teachers

3. A UC professor who teaches the group of pre-service teachers (and has guided them in the preparation of the lesson plan.)

4. "Resource Person" ("knowledgeable other") with relevant knowledge from other institutions, such as universities, textbook publishers or municipality

5. Other teachers and UC professors at invitation (at least 1 in addition to those mentioned above - acting as moderator during the following discussion)

6. Other pre-service teachers at invitation

Observers are usually standing at the back of the class or along the walls to the side and interfere as little as possible. During periods in which pupilss work alone or in groups, they circulate quietly in class in order to gather information about pupils' work in relation to the hypotheses under investigation. Pupils are prepared beforehand that there will be observers present and they have to work as usually under the guidance of the pre-service teacher.

All observers have pre-read the lesson plan before the observation begins. The three main observers (2. 3. and 4. above) agrees to a gross partition of questions from the lesson plan, so that they do not all focus on the same during the observation.

3. REFLECTION

Immediately after the lesson all participants (1-6 above) attend a joint meeting where people share observations and reflections concerning the lesson.

The meeting is led by a moderator, usually an experienced teacher or UC professor (from group 5 above). The meeting begins with a panel that speaks, and sits at a table, in the order given below. (Usually all participants sit at the same table, but in case of many participants, the panel sit in front of the others).

The panel consists of:

1A. the pre-service teachers who have taught

1B. other pre-service teachers from practice group

2. Cooperating teacher

3. UC professor responsible for pre-service teacher guidance.

4. The resource person

5. The moderator

The moderator normally do not enter into the conversation, but makes sure it remains focused on the questions and hypotheses raised in the lesson plan - and that the conversation always takes place in a constructive and collegial tone, focusing on the lesson plan and pupil learning.
The moderator gives a welcome speech and briefly reminds everybody of the principles and process of the meeting. He gives the floor to the panel in the order above (each, approx. 3 minutes):

1A: provides some personal reflections regarding lesson in relation to the lesson plan
1B: present two to three observations from working to prepare the lesson plan
2: present two to three of observations based on his experience with the class and in relation to the lesson plan questions.
3: present two to three observations relevant to the lesson plan questions
4: present two to three observations relevant to the lesson plan questions

Note that in this initial phase, no complicated or concluding reflections should be ventured.

The moderator then organizes a discussion of the issues raised by the lesson plan, where all observers have the opportunity to contribute and comment. These interventions should be short, concise and constructive - usually in form of **questions** posed to the pre-service teachers, and always based on **concrete observations of the lesson** (and **never** "knowingly such-and-such would I have done"). Between each intervention 1A and 1B is given opportunity to comment or ask clarifying questions to the observations. This "free" part of the discussion takes approx. 25 minutes (the moderator takes care to stop this part approx. 5 minutes before the meetings’ scheduled end time).

Finally a resource person is given the floor for approx. 5 minutes, intended to sum up an important point from the observation and discussion. The resource person generally acts more observant than active for the preceding discussion, in order to make this summarization from an "external perspective".

Table 2 Translation of lesson plan template

Lesson Plan

School and class:

Date:

Teacher:

Lesson Study Group:

Mathematics topic:

Title:

Goal:

Attainment targets (in accordance with national course of study):

Background Information:

Why we have chosen this topic for lesson study?

Why is it important for pupil learning to have this lesson now?

Why we have chosen the following main activities?

What teaching strategies are needed for this lesson?

Teacher Academic goals:

Which teaching strategies, methods, etc.., would we like to explore and try out in this lesson?

How would we like to explore and test these strategies?

What ideas / hypotheses do we make regarding the use of strategies in relation to pupil learning?

Lesson Description:

Learning activities	Expected duration	Expected pupil responses	Teacher support	Evaluation Signs - and data

Evaluation:

Didactic transposition of mathematics and biology into a course for pre-service teachers: A case study of 'Health - risk or Chance?'

Abstract This paper represents work in progress on the didactic transposition resulting in an interdisciplinary course for pre-service teachers. It is shown how knowledge for teachers can be described using the anthropological theory of the didactic, and the first steps of an analysis of the course's genesis is presented. Firstly, the 'knowledge to be taught' chosen for interdisciplinary consideration is seen to be determined by the "noosphere" outside the teaching disciplines. Secondly, a more internal transposition takes over, attempting to supply, and create a meaningful bi-disciplinary connection. The resulting course description is presented, and furthermore an 'a priori' analysis of a Study and Research Path is briefly discussed as a means to satisfy many of the constraints put on 'taught knowledge'.

Introducing the problematic

Pre-service teachers are to acquire didactic knowledge that enables them to help pupils acquire mathematical and biological knowledge in lower secondary school. This is a well-known plight of prospective teachers if we regard only one discipline at a time, and those who educate teachers have for many years' expounded and enacted didactic knowledge that helped pre-service teachers do this. The challenge for those who *educate* teachers is thus on a meta-level; it is a nested challenge, which inherent intricacies they are not free to dismiss.(Chevallard, 1989) This challenge has in Denmark traditionally been meet by providing pre-service teachers with greater mastery of the single (scholarly) discipline, and, over the last 20 years, increasing amounts of pedagogic and didactic knowledge have been integrated into the teacher education curriculum. However, in the last ten years, increasing demands have been put directly on teachers in secondary education, to combine different disciplines into coherent teaching which is interdisciplinary in some form or another. (See fx Hansen & Winsløw, 2011 regarding upper secondary eduation, and ; Undervisningsministeriet, 2009 regarding lower secondary) On the other hand, those who *educate* teachers have not been expected to do the same to any great extent. Therefore newly graduated teachers have largely been left on their own to do the interdisciplinary synthesis. Furthermore it is worth noting, that the majority of existing research is concerned with the direct design and implementation of interdisciplinary education, or the evaluation of interdisciplinary teaching compared to ordinary teaching.(See e.g. Berlin & White, 2010) Very few consider the nested problem of interdisciplinarity *in teacher education.*

I begin by presenting the theoretical framework of the Anthropological Theory of the Didactic (ATD) to express the challenge of helping others acquire interdisciplinary teacher knowledge. And then I provide a case from a Danish project (named ASTE) developing a new teacher education program, where selected knowledge from "the teaching of mathematics" and "the teaching of biology" has undergone transposition into an interdisciplinary course under the heading 'Health - Risk or Chance?' The subsequent analysis considers two parts: a) the transposition process from existing national curricula to the specific course curriculum and course description. b)The design of a Study and Research Path (SRP) (Chevallard, 2006) for pre-service teachers. Part a) is done "a posteori" while part b) provides an 'a priory' analysis of the SRP design, and a discussion regarding its appropriateness to instil, in pre-service teachers, didactic knowledge regarding the combined disciplines.

Framing the problematic in ATD:

In ATD, knowledge is modelled using the notion of praxeological organisations. (Chevallard, 1999) Praxeologies are the combination doing and knowing. When presented with a task, humans can employ a technique to handle that task. Task and technique is called *praxis* and what reasoned discourse and theorizing can be done relating hereto is called *logos*. One cannot exist without the other, although either may be very simple or underdeveloped. When considering teacher knowledge (Huillet, 2009), a distinguishing is made between knowledge to be taught and the knowledge to help others acquire that knowledge. The former I will abbreviate KO, where K stands for some "declared Knowledge" (cf. (Chevallard, 1989, p. 8) and O for praxeological Organisation, and the later I abbreviate DO: "Didactic Organisation" The knowledge is usually declared in a form belonging to an established discipline (in this case mathematics or biology)

In an interdisciplinary course pre-service teachers are to engage in a number of lessons (very broadly understood), where some kind of disciplinary synthesis is apparent, and the intention is that the didactic organisation of the teacher educator (DO_E) will give rise to (inter)disciplinary and didactic organisations among the pre-service teachers (KO_{PS} *and* DO_{PS}). It is important to stress that KO's and DO's are intimately connected, and therefore DO do not refer to general pedagogical issues.

Thus is the challenge for the teacher educator: To build DO_E which helps pre-service teachers to build their KO_{PS} and DO_{PS} which again will help pupils build their own praxeologies regarding the involved disciplines (KO_P). The general research question then becomes: *How is knowledge (KO_{PS}*

and DO_{PS}) for an interdisciplinary course for pre-service teachers compiled, and what conditions do the characteristics of such a course put on DO_E?

The following paragraphs pave the way for a reformulation into the case-specific research question, and each of the two parts of the analysis will be preceded by a short section detailing further theoretical tools needed to deal with the specificity of each.

The Case Context, Data and methods for the two parts of the analysis

Teacher education in Denmark takes place at University Colleges (UC) where pre-service teachers study the "teaching-disciplines" of lower secondary school. It is an education directed specifically towards the profession as a teacher, and the courses can roughly be divided into school-discipline specific ones and general pedagogic ones. I will concern myself only with the school-subject specific ones, which feature an integrated study of the related "scholarly knowledge" (KO) and its didactics (DO). To become a certified teacher of e.g. mathematics, the pre-service teacher needs to take four 'math'-courses valued ten ECTS[1] each. (Which together with other courses makes a total of 240 ECTS for the entire degree) The norm is for a pre-service teacher to study *three mono-disciplinary* school-disciplines, thus becoming a certified lower secondary teacher of e.g. mathematics, biology and history. The course under consideration in this paper is situated in the special program *ASTE,* which offers pre-service teachers to become certified in *four* school-disciplines: mathematics, physics/chemistry, biology and geography. The central idea is to make a recombination of elements from existing mono-disciplinary teacher education courses, utilizing synergy between the mentioned, very much related disciplines, and thus making "room" for the extra school-discipline certification. The recombination resulted in four courses named: "Energy and Climate" (covering elements from geography and physics/chemistry), "Sustainability" (biology and physics/chemistry), "Nature playing dice" (mathematics and physics/chemistry), and "Health - risk or chance?" (mathematics and biology). It can be gleamed from the course-names that those involving mathematics, has stochastic elements as focus, the reasons for which will become apparent during the analysis of the didactic transposition below. It should also be remarked that the math-perspective has been given a slight precedence over the bio-perspective due to limitations of space.

[1] European Credit Transfer System

Data for part A, regarding the transposition of knowledge for the course selected as case for this paper, comes in the form of audio recordings of meetings, as well as documents, both external (e.g. curricular guidelines) and those produced by the participants internal to the development of the special educational program. Both recordings and documents have been inventoried and coded using the qualitative data analysis software NVivo. Excerpts offering insight into the transposition process have been coded according to its (disciplinary) position or lack thereof, and impact on the realized course curriculum and course description.

Data for part B, the design of the SRP, is a conglomeration of background reading of textbooks, research papers, web-based "information material" and discussions during a ph.d. course (2014). Data for the design proposal is necessarily diffuse, as it seeks to describe paths possible and desired, intended to satisfy a number of design requirements. Not the paths actually taken by pre-service teachers.

Part A: Analysing the didactic transposition resulting in "Health - Risk or Chance?"

In this part I answer the case-specific research question: *How is knowledge (KO_{PS} and DO_{PS}) from teacher education curriculum in mathematics and biology selected and combined to produce the course: 'Health - Risk or Chance?'*

The didactic transposition of knowledge can be divided into four steps (Figure 1):

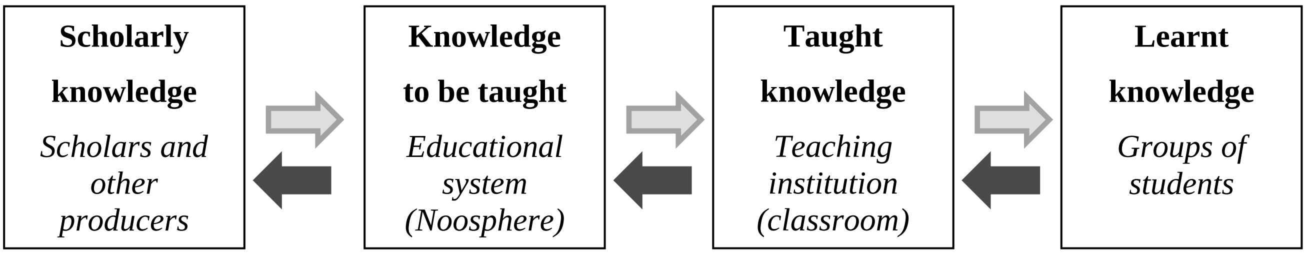


Figure 1: The didactic transposition process (Bosch & Gascón, 2006)

Knowledge is created at some point, here called "scholarly knowledge" and then it is selected by the educational system to be taught to some students. In this process the knowledge changes. Although the process most certainly goes from left to right, there is a definite feedback indicated by the arrows going in the other direction. In this analysis I take a closer look at the 'knowledge to be taught', which to a large degree is defined within the educational system, or the institutions entrusted to provide education. Nevertheless society in a much larger sense has a say in what should be taught. The "noosphere" is all actors having a say regarding what to be taught. (Politicians, researchers, public and private interest groups etc.) Tracing the genesis of "Health - risk or chance?” it is seen that the transposition process inside the educational system can be divided into more detailed steps (Figure 2):

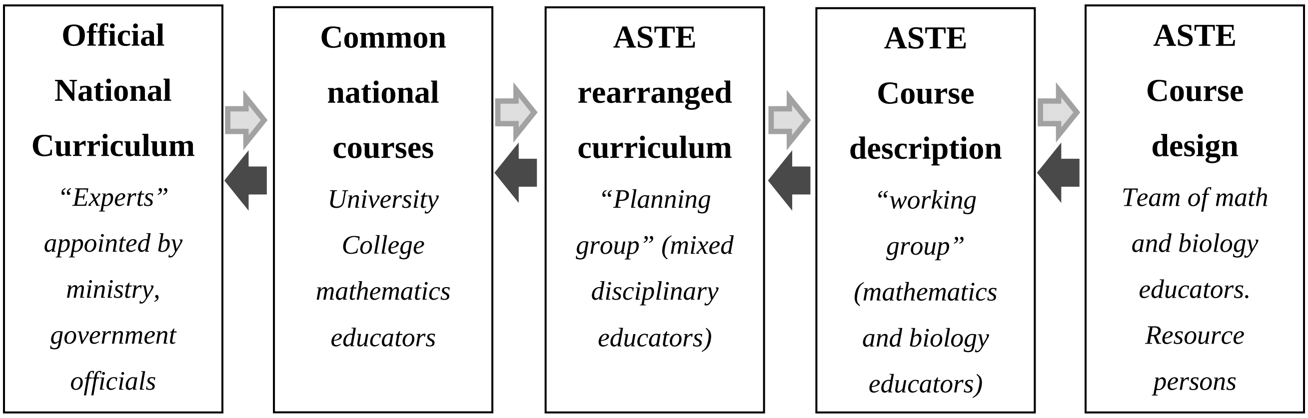


Figure 2: Expanded ‘Knowledge to be taught’

The Official National Curriculum (ONC) for teacher education describes mathematics using what is called, four “areas” of competence: *Topics*, *Ways of Working and Thinking*, *Math Didactics* and *Didactic Methods*. The ONC is permeated by the idea that you can describe curriculum in terms of “competencies” (Blomhøj & Jensen, 2007). E.g. *Math Didactics* is described as: ‘The scientific domain encompassing the study of actual mathematical teaching and learning, as well as development of a theoretical basis for math teaching.’ and it has the goal of enabling the pre-service teacher to “describe, analyse and asses teaching and learning of mathematics with the support of didactic theory.” (Uddannelses-og-Forskningsministeriet, 2015, Bilag 2)

To further specify what knowledge these competences actually cover, the ONC lists around forty paired elements specifying “target knowledge” and associated “target skill”. E.g. under *Math Didactics* it is stipulated that the pre-service teacher must *know* “how math curricula changes with time and how it is related to societal and scientific challenges.” Associated hereto the pre-service teacher can skill wise “relate to existing curricula for mathematics education in relation to mixed ability instruction.” (Uddannelses-og-Forskningsministeriet, 2015, Bilag 2) Some readers may find the example pair somewhat non sequitur, but as all legal documents do, the ONC requires interpretation: What does it mean to ‘relate’ to curriculum?

It is noteworthy that the “competency” description does not stand alone. The specification into terms of ‘knowledge and skills’ render “competency”-description somewhat superfluous, and more significantly, the pairs of “knowledge and skills” lend themselves readily to praxeological analysis: The “target skill”-requirements all point to something the pre-service teacher has to be able to do, which is the same as solving a task using a technique (this is *praxis*). Likewise the “target knowledge” can be interpreted as a specification of the *logos* the pre-service teacher should have,

making this an example of $DO_{PS.}$ Elaborating the example it is evident that ‘to assess whether an exercise from an old math-textbook is relevant for high ability pupils’, is a didactic task and technique for the pre-service teacher, which can be informed by knowledge of curricular change. In terms of the presented ATD framework I argue that ONC declares teacher knowledge in the form of praxeological organisations (DO_{PS}) to be taught by teacher educators (using DO_E)
‘Knowledge to be taught’, as written in the ONC, is considered by an assembly of mathematics teacher educators[2] (step two in Figure 2), one from the math department at each University College. At this step roughly half of the praxeologixal organisations are selected to be taught in two *Common national courses* for all math teacher education programs. (A parallel process takes place regarding biological knowledge to be taught) The remaining praxeological organisations are considered *locally* by the math educators at each University College, and arranged into another two courses. (This is a ‘semi-step’ not depicted in Figure 2) This is where the ASTE project enters into the transposition process: Principally ASTE could choose to make any *rearrangement* of the praxeological organisations left for local determination and combine them with appropriate ones from biology. (Appropriate in the sense of being well suited for synergy between the two teaching disciplines) This did not happen due to institutional organisational constraints: The ASTE courses could only replace one of the locally determined math courses; “Special needs pupils and mathematical aids” or “Evaluation and stochastic processes”, because one of them had already been written into the local curriculum. (The above mentioned ‘semi-step’ of the transposition process) Which one it actually was, took a while for the ASTE-developers to figure out, as the local curriculum development process ran alongside the ASTE endeavour.

> “Uhh, we have just solved it! ... Yes it fits, so it is stochastics which is the common topic and then some different competencies...” (ASTE Curriculum Planning, May 2, 2013, Time index 2:09:50-2:10:21)

The developers had only briefly considered mixing stochastic and biological topics beforehand:

> ”The use of genetics in connection with biotech could be reserved for the bi-disciplinary course … then you could also, if they [the pre-service teachers] had already had a little about genetics, develop the aspect of probability in mathematics ... also combinatorics, like with the colour of eyes” (ASTE Curriculum Planning, May 2, 2013, Time index 1:56:40-1:57:18

[2] ”Den Nationale Faggruppe”

Even though the mathematical praxeologies regarding “modelling”, especially “functions”, had been the favourite connection between math and biology, the development was now bound to combine statistical aspects of mathematics with the biological elements:

> “It just has to be very special kinds of models, it should not be function-models, and it must have something to do with gathering data, that is, statistics or probability, right? At least if we have to cover “our” [praxeological organisations]...” (ASTE Curriculum Planning, Mathematics Educator, May 2, 2013, Time index 2:53:35-2:54:00)

> “What kind of truth is it when we say carrots are healthy? What does it really mean? What is the data founded on? Here you can work with all the mathematical methods and models you like in order to understand. ... Uncle Sofus smoked cigars all his life and did not die, ergo tobacco is not lethal. It is this kind of problematics...” (ASTE Curriculum Planning, Biology Educator, May 2, 2013, Time index 2:54:42-2:54:00-2:54:56)

This resulted in the following ‘knowledge to be taught’ to the pre-service teachers (Table 1) which can be viewed as very general, but none the less paired descriptions of the knowledge and praxis block of intended praxeologies.

Table 1: Biological and mathematical ’knowledge to be taught’ (“math” indicated by italics)

Logos: The student has knowledge of:	**Praxis:** The student can:
Science education, research in didactics of science	develop teaching in biology on the basis of science didactics
Natural sciences use in social, technological and business contexts and didactic knowledge of the involvement of the outside world in education	include examples of the application of science and technology in society in the teaching of biology
Relationships between structure and function at all levels of organization in living organisms, especially human anatomy and physiology and health concepts	plan, implement and evaluate lessons that promote students 'understanding of the relationship between structure and function of human anatomy and physiology, as well as allowing students to actively use the acquired knowledge and insight in relation to their own and others' health
Recent research in the natural sciences	include examples of recent scientific research in education
Science educational resources such as textbooks, multimodal and web-based learning resources, science centers, outdoor spaces, businesses, museums, etc.	Using different teaching resources
Food and biotechnological production: biological basis for the opportunities and consequences for health, environment and nature, including knowledge of educational resources in this topic, such as science centres, companies and research institutions	Plan and conduct courses that make pupils able to explain biological processes in production and put them in perspective in relation to the ecological, developmental and social perspectives.
Statistics, systematic collection, description, analysis and evaluation of data, including IT and the use of descriptors of location, spread and correlation as well as statistical tests and their use.	*Analyze systematically collected data using statistical descriptors and diagrams. Use tests as a basis for the teaching of statistics including using ICT.*
Mathematical problem solving	*handle problems by detecting, formulating, defining*

	and solving mathematical problems by systematic choice of strategies and tools.
Mathematical representations	*use mathematical modes of representation to understand, use, select and translate various forms of representation, including understanding their inter-relationships, strengths and weaknesses.*

Following the selection of praxeologies by the planning group, a “working group” of ASTE developers was formed (not identical to the planning group). This group produced through a series of meetings and document exchanges, a course description carrying over a great deal of the ideas hinted in the last citation above (Table 2):

Table 2: "Health - risk or chance" course description

The module includes basic knowledge of the human body's physiology, anatomy and health, both individually and in the larger context. Working with risk assessment, distribution and prediction of health-issues include basic knowledge of statistics and statistical tests. The module is built around three themes: **Theme 1**: Normality Concepts in relation to e.g. weight, height, fitness and longevity will be treated physiologically as well as mathematically. This will include statistical investigations with data collection, statistical descriptions, representations and processing, for example in relation to physiological training. IT will play a key role in these investigations, which basically will be problem-oriented. **Theme 2**: Analysis of the spread of various diseases and health conditions, both in time (a historical angle) and space (north-south dimension). Including measures for population growth and efforts to limit growth. In relation to the analysis, statistical tests will be executed in order to assess the risk of e.g. development of certain diseases based on genetics A historical analysis of biology books for the Danish school for an assessment of the presented health problems, health didactics and sex education. In relation to this is also the study of changing curricula, together with the current mathematics curricula in elementary school in order to see connections to social and scientific - especially health - challenges. **Theme 3**: Selected human physiological themes

Concluding remarks on part A

This brief account of the transposition process show that the deciding factors for KO_{PS} and DO_{PS} selected for the course “Health –risk or chance?” resides primarily outside the ASTE project. Decisions taken at the first two steps of the expanded transposition process (depicted in figure 2), and in at another “semi-step” by local teacher educators, severely narrowed down the possible combinations. Regarding the last two transposition steps, it can be said that the presented course-description expresses the ASTE-working group's attempt at turning "left over" 'knowledge to be taught' into a meaningful course, and it still remains to be seen if the course designers will be able to make it meaningful for the pre-service teachers. The transposition process has thus put quite daunting conditions on DO_E to be developed. It was not clearly perceived prospects of synergy, either from the perspective of mathematics education or biology education, which dictated the combination of statistics and health to be an interdisciplinary field in which teacher education could flourish. The teacher educators are thus required to 'break new ground', and in the following part I present the SRP design, which the educators will employ to, at least partially, handle this challenge.

Part B: Design of a bi-disciplinary SRP

A Study and Research Path is didactic mechanism, or teaching proposal, where pupils set out to answer a grand question in a semi-autonomous fashion (See e.g. Chevallard, 2009 or; Winsløw, Matheron, & Mercier, 2011 for more details)

The central requirement for a SRP is the necessity for pre-service teachers to have enough means to start the study and deal with the initial grand question. The fundamental objective for the teacher educator is to secure that responsibility to answer the question is assumed, as well as responsibility for the majority of decisions of the study process. The SRP is initiated by a question with strong generating power, capable of imposing numerous derived questions leading to various elements of 'knowledge to be taught'. Instead of starting from "classic content" established in the strict framework of a discipline or a body of knowledge, the proposal consists in ideally "covering" curricula with a (or several sets of) SRP(s) without a specific connection to classic content. The study of these SRP's should cause the encounter with the intended knowledge, and other knowledge, and thus features a high degree of widening compared to the majority of study processes.(Rodríguez, Bosch, & Gascón, 2007) It is important to note that SRPs are in this manner "naturally" interdisciplinary.

When implementing a SRP, it provides a framework for DO_E and at the same time suggests a possible answer to the required interdisciplinarity. The central challenge is to design a generating question for the SRP which will spawn sub questions that will make pre-service teachers become knowledgeable about both KO_P and DO_{PS}, and in the process also develop their own KO_{PS}. The idea is that:

> "Setting up a ''scene'' in the [...] classroom, with a crucial ''opening question'' in the beginning, may provide a rich field to initiate a dialogue and give the opportunity for knowledge conflicts and negotiation of meaning" (Patronis & Spanos, 2013, p. 1997)

Design requirements for the SRP dictates that it must cover a theme which is exemplary for the teaching of “the nature of science and mathematics” (Gericke, 2009, pp. 7-8) and exemplary for the teaching of similar themes related to biology and mathematics. The SRP theme must fit into the overall descriptions and requirements of “Health – risk or chance?” and the theme must be clearly related to descriptions and requirements (curriculum) for the math and biology disciplines in lower secondary school. (That is, its relevance must be obvious to pre-service teachers). Furthermore the generating question must give rise to investigations of both mathematical and biological organisations, as well as their associated didactic praxeologies, as related to the teaching of children in lower secondary school.

Proposed design and the first steps of analysis

In this paragraph I only just present the generative question Q_0 (actually used in the course implementation) and its ‘a-priori’ derived questions revolving around the illness *diabetes*, which disrupts human blood sugar regulation. The result is given in the “tree-diagram”-form (Hansen & Winsløw, 2011) (Figure 3)

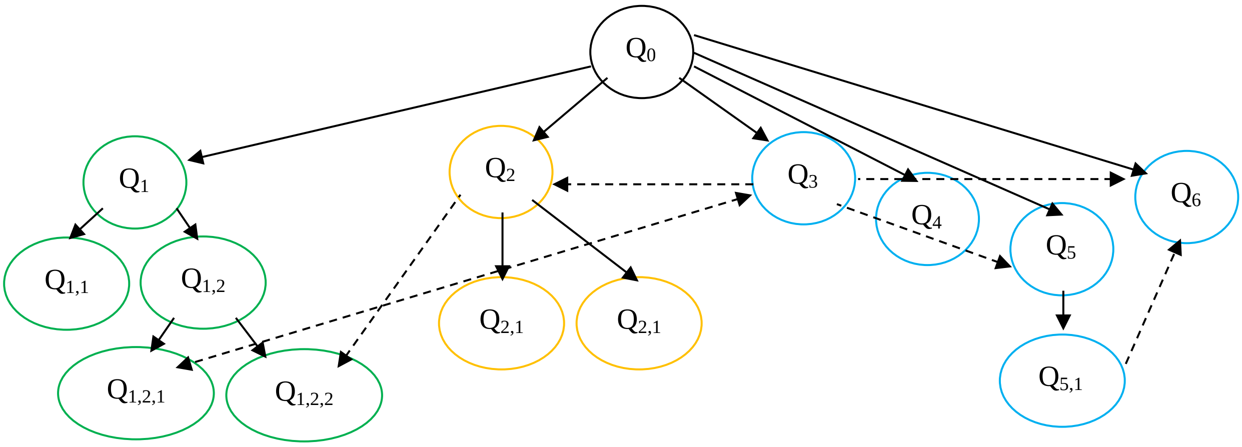


Figure 3: Tree diagram showing the generating question and the first few sub questions. Green and yellow colour respectively indicates questions, and therefore disciplinary organisations, from biology and mathematics, whereas blue colour indicates questions to generate didactic organisations. Dashed arrows indicate that the receiving question is expected to draw on knowledge from the answers to originating questions.

Q_0: Why is diabetes a problem for school and society?

Q_1: What is diabetes?

Q_2: How to describe and investigate the <u>distribution</u> of diabetes?

Q_3: What is written about diabetes in school texts? (Curriculum, textbooks, etc.)

Q_4: How are known school lessons on diabetes? (e.g. in published lesson studies)

Q_5: Why choose the theme “diabetes”? Why should it be a concern for schools?

Q_6: What could be suitable *settings or scenarios* wherein to learn about diabetes?

$Q_{1,1}$: What is the consequences of diabetes?

$Q_{1,2}$: What is the cause(s) of diabetes?

$Q_{1,2,1}$: How has the causes of diabetes changed over time?

$Q_{1,2,2}$: How is possible causes identified?

$Q_{2,1}$: Who is afflicted with diabetes? (Where do they live (geographic distribution), how old are they age-distribution, socio-economic distribution...)

Q2,2: How many gets diabetes? (Distribution in time)

Q5,1: What do children know about diabetes? What are their experiences? Will diabetes be a motivating theme?

It is of cause central to elaborate why this diagram presents important and likely features of the SRP, and in particular why some questions are foreseen to make connections across the disciplines, but due to the limited space of this paper, I have to let the network of questions speak for itself, save for the considerations mentioned below

Considerations regarding SRPs as didactic organisation

The generative question is of paramount importance as it is likely to be the only part of the SRP that the educators have any direct control over. The chosen form is actually two questions in one, and point the pre-service teachers towards making a disciplinary investigation and a didactic investigation. In fact they are directed to consider the first two (or two and a half) steps in the didactic transposition process (Figure 2). They need to review the scholarly knowledge and the knowledge to be taught while thinking ahead to actual lessons. It is ideally necessary for pre-service teachers to concern themselves with all parts of the transposition process; in that respect pre-service teachers and teachers in general do not differ from researchers of didactic transposition processes. The (perhaps only) difference is that the former has to act out the final steps of the transposition; at some point have to perform actual teaching.

Suitably framed via the generating question, SRPs has the potential as part of DO_E to force pre-service teachers into doing on their own, what they are indeed expected to do, on their own, as full members of the teacher profession. Teacher educators who seek to use SRPs, are obliged to perform an a priori analysis, using consecutive reformulations of the generative question, constantly evaluating the potential for realisations of ‘knowledge to be taught’. This could also be the case for other forms of “project”-work in teacher education, but the inquiry-process of SRP’s, which are based on questions, rather than works to be visited, is helpful in overcoming a too narrow “focus” on single parts of the transposition.

Concluding remarks

Part A of this paper showcases the peculiarities of didactic transposition which bring disciplines together in unexpected combinations. Not arbitrarily, but because forces in the ‘noosphere’ had priorities which left only certain elements for the course ‘Health –risk or chance?’ Part A answers the research question while Part B touch upon the beginning of the internal didactic transposition of turning the course description into ‘actually taught knowledge’, for which a study and research path is presented as an element in the didactic praxeology of the teacher educator.

The direction and autonomy of interdisciplinary study and research paths in teacher education

Abstract This paper presents a case study of didactic infrastructures to direct Study and Research Paths (SRP) in teacher education within the context of interdisciplinary inquiry. The disciplines of school mathematics and school biology, and their didactics, are made to interconnect through the investigation of a generating question concerning the illness diabetes. The resulting interdisciplinary knowledge as evidenced through students written diaries is analysed using the Anthropologic Theory of the Didactic and shows the challenge of combining two disciplines and their didactics at the same time. Two particular forms of didactic infrastructure to guide the self-sustained process of SRP are proposed and scrutinized: *Selective picking* and *Side questions*. Selective picking is shown to be a promising, yet indirect, infrastructure to steer the SRP without taking away the desired autonomy of the students. Side questions, initially proposed by Ives Chevallard, are considered in light of the case, and a number of suggestions for their characteristics and use are put forward.

Introduction

A Study and Research Path (SRP) is a didactic design format, in which students and teachers set out to answer a generating question with more or less autonomy expected from the students (Chevallard, 2006, 2009; Winsløw et al., 2011). It has been proposed as a game-changer in the teaching of mathematics (and other disciplines) (Chevallard, 2012), that could move teaching into a new paradigm of “questioning the world”: the curriculum is no longer delineated by content described as particular *works* to be visited, but it is instead expressed as a number of generating questions to be studied. A stronger emphasis on important questions could, according to Chevallard, facilitate a departure from the usual disciplinary compartmentalisation of education. Indeed, a societally important question is not often answerable within a single discipline, so SRPs could be especially attractive in teaching contexts where interdisciplinary inquiries are desired or at least possible. And so, the use of SRPs in interdisciplinary settings have been examined by a number of other researchers: Barquero, Bosch, and Gascón (2013) involved mathematics and population dynamics in an inquiry into the growth of animal populations (See also Barquero, Bosch, & Gascón, 2007) The SRP implemented by them involved a number of different teaching formats, including lectures, group work and discussions where the students increasingly were given more and more autonomy. New directions of the inquiry process were decided during “academic conferences”, after group presentations of work done so far. Jessen (2014) considered a setting involving mathematics and biology as the partaking disciplines, but where the students worked individually with very limited teacher interaction: The students investigated a set of questions on the dosage and functioning of a painkiller drug and the students’ progress was mainly supported by written feedback from the teacher. Others, like Hansen and Winsløw (2011) and (Thrane, 2009) looked at history and sports respectively in connection with mathematics, both in settings where students prepared written reports to document the process of questions and answers.

These studies all take great interest in the knowledge generated by students, and particularly in the connections developed between the constituent disciplinary domains. Does one discipline support the other? Do they integrate well, or do they give answers to the generating question only in a parallel fashion? What they only scarcely elaborate on, is the means by which the teacher seeks to bring about the *Herbartian learning environment,* needed for a fruitful inquiry process. The notion of *Herbartian attitude* was introduced by Chevallard (2012) to express a propensity to engage oneself with unanswered questions, to take real or professional interest in pursuing it, to find and examine partial answers, and to generate new derived questions.

The self-sustaining study and research process which could ideally be the result of such an attitude does not emerge automatically or easily. As pointed out by Bosch and Winsløw (2015) at least three questions remain open when it comes to the practical realisation of self-sustained research and study processes (here rephrased to reflect disciplinary generality):

I. What are the didactic and disciplinary infrastructures (and resources), as well as the associated knowledge, required for the design, monitoring and evaluation of sustainable study and research processes?

II. What are the institutional conditions needed for teachers to design and implement sustainable study and research processes, and for students to engage in them?

III. What kinds of constraints or even obstacles do institutions and societies commonly offer to such processes?

In the following paragraphs, we examine the first question in the case of a SRP experimented with teacher students in a module shared by mathematics and biology. Question II and III will only be commented on in light of the local institutional conditions.

Design – context and theory

The case SRP was designed, implemented and evaluated by two teacher educators from the disciplines biology and mathematics. The mathematics educator is the author of this paper. When the authorial “we” is employed in the following, it reflects joint considerations of both involved educators. The students participating in the SRP were pre-service teachers in their fourth semester of a special program called *Advanced Science Teacher Education* (ASTE). This ASTE-program has as its core a number of interdisciplinary courses, one of which is called “Health – risk or chance?” The course covers curricular elements from the biology and mathematics teaching disciplines as prescribed for lower secondary teacher education in Danish university colleges.

A central requirement for the SRP is the necessity for pre-service teachers to have enough means to start the self-sustained study and deal with the generating question. The educator has to “know what the pre-service teacher knows”, which in the Anthropological Theory of the Didactic means knowledge of the *praxeological equipment* of the students (See e.g. Chevallard, 1999 for further details on praxeologies). The fundamental objective for the teacher educator is to secure that responsibility to answer the question is assumed, as well as responsibility for the majority of decisions of the study process. The generating question should have the potential of enabling the study community to ask numerous derived questions leading to “contact” with various elements of course curricula. A particular challenge to designing a generating question for SRPs in teacher education is that the pre-service teachers, during the study and research process, should pursue the question on several specific levels: Their own biological and mathematical praxeologies should be strengthened, their grasp of lower secondary pupils’ praxeologies should develop, as well as the didactic praxeologies to direct lower secondary pupils’ study along the same or similar paths.
Letting teacher students themselves carry out a SRP have, among other elements, been experimented by Barquero, Bosch, and Romo (2015) to deal with the above challenges within teacher education in the monodisciplinary setting of mathematical modelling. Furthermore the SRP must cover questions which are exemplary for the teaching of “the nature of science and mathematics” (Gericke, 2009, pp. 7-8) and more generally for the teaching of similar questions related to biology and mathematics. Finally, in the concrete case, the SRP must fit into the overall descriptions and requirements of “Health – risk or chance?” and the question must be clearly related to descriptions and requirements (curriculum) for the mathematics and biology disciplines in lower secondary school. An important supplementary requirement is that this relevance must be visible to the teacher students.

Here we arrive at an evident contemporary obstacle to SRPs in general: Curricula are presently *not* formulated in terms of questions. In Danish teacher education, curricula are formulated partly as competences (Blomhøj & Jensen, 2007) partly as *knowledge goals* and s*kill goals* where the latter part most closely resembles *works* to be visited. Educators are naturally concerned whether SRPs will succeed in connecting students to the works. SRPs may be an attractive and intellectually desirable didactic infrastructure, but is it efficient in terms of current goals set by society? Nobody knows. Bosch and Winsløw (2015, p. 29) point out that, as in the case of actual research processes,

> "… during the inquiry process, especially when it is not tightly guided, many detours and dead-ends will appear, with the examination of potentially useful answers that will be tested then finally discarded."

Thus, SRPs may run counter to the prevailing didactic contracts, generating a fair amount of scepticism, uncertainty and critique from the students, as well as from members of the noosphere. These expected reservations compelled us to refrain from executing the whole course as SRPs. This, together with the above mentioned need to make sure the students had the means to initially face the generating question, prompted us to limit the extend of the SRP to 20% of the workload in the *Health – risk or chance?*-course.

Design process

In order to device the crucial generating question, we reviewed the course description and the required curricular elements with the above mentioned general considerations in mind. The course is described as being composed of three overarching themes, where one, quite ungainly, reads:

> "Theme 2: Analysis of the distribution of different illness- and health-issues, historically and geographically, including measures of population growth and initiatives to limit such growth. In relation to this, statistical tests will be performed in order to evaluate the risk, e.g. of developing particular diseases, based on genetic analysis."

Obviously a question revolving around some specific health disorder would be ideal, but which? *Diabetes*, which was finally chosen, possessed a number of promising features: It afflicts both pupils in secondary school and students in pre-service teacher education. Many students know someone who is afflicted with diabetes and thus are likely to be able to identify themselves with the problematic condition. It is a disorder whose causes are not simple or fully known: some have to do with lifestyle, others with genetics. As a lifestyle related disorder, it lends itself readily to statistical investigation, and as an autoimmune disease it relates to human physiology and bodily functioning, corresponding well to several of the knowledge goals and skill goals proscribed by the curriculum. The proposal of diabetes was discussed among four educators from the ASTE-education program, and an external scientist doing research on diabetes was consulted. The external scientist could point to current statistical and medical research in the field, assuring us that rich *media* existed which the students could study. We also reviewed secondary school textbooks and other non-research media (e.g. internet sites) to make sure didactically oriented media were available. A first proposal for the generative question was formulated:

Q_0: How does mathematics and biology in lower secondary school contribute to children's knowledge concerning diabetes?

This question purposefully mentions both involved disciplines, as well as the institutional target level in the hope of compelling the students to make mathematical, biological and didactical inquiries into the diabetes theme. We note that Danish lower secondary school mathematics includes elements of statistics. This formulation, together with an *a priory* analysis of possible derived questions, was discussed with other researchers at a course for Ph.D.-students. The suggestions received prompted us to rewrite into the following simpler and less explicitly directed first question:

Q_0: Why is diabetes a challenge for school and society?

The reasoning was that it would be superfluous to mention the disciplines, both because they were implied by the overall course setup, and because it would somewhat diminish the interdisciplinary intention, making it likely that two parallel, but essentially separate, paths would be followed. The latter problem was in fact observed in Hansen and Winsløw (2011). The incorporation of "society" was made to avoid a narrow focus on what pupils in lower secondary school might be able to learn about diabetes, opening up for the students to go as deep into the problematic as their own capacity allowed. A societal focus - often considered in terms of "data" - was believed to have the potential to generate needs for elements of statistics and at the same time avoid an investigation of only pedagogical challenges to teaching. At an intermediary stage Q_0 was phrased with the word *problem* instead of *challenge*, but was changed due to very specific connotations the students could have for this term, especially within the didactics of mathematics.

The next step in the design process was for the two educators to undertake a final a priori analysis of which sub-questions could likely be derived from Q_0. Which sub-questions would draw on answers to other questions? Which disciplines would the questions and answers likely draw on?

This analysis also served to prepare us for the upcoming lessons, making us aware of knowledge we would have to study in preparation, including questions which we ourselves found difficult to answer or find suitable media for. The sub-questions and their interrelations can be visualised in the "tree-diagram"-form (Hansen & Winsløw, 2011), shown in Figure 1.

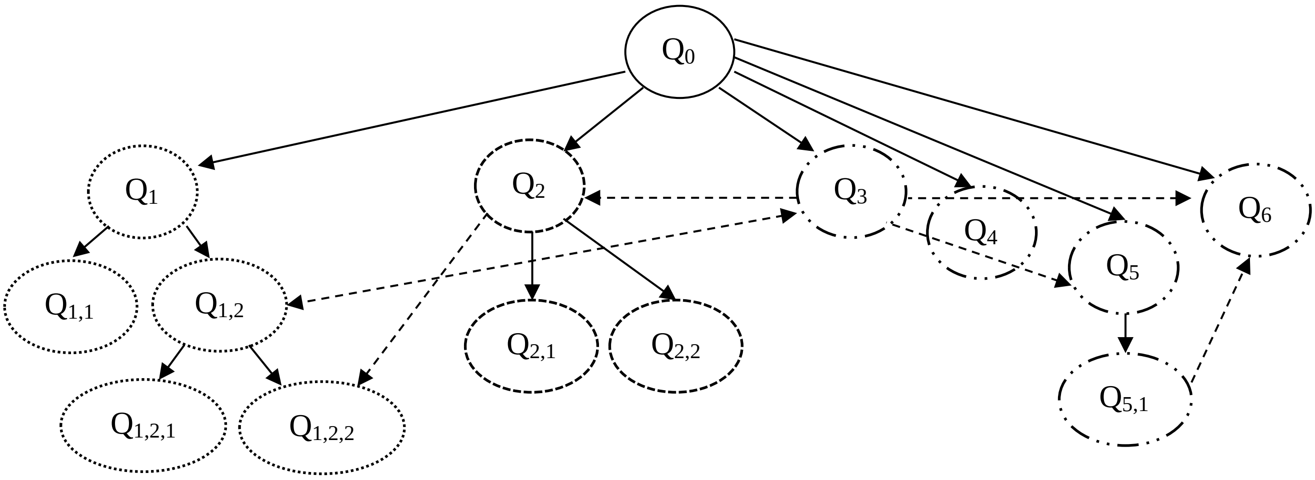


Figure 1: A priori analysis: Tree diagram showing the generating question and the first sub questions. Short and long dashed circles respectively indicate questions judged as belonging to biology and mathematics respectively; whereas combination dashed circles indicate questions of a more didactical nature. Dashed arrows indicate that the receiving question is expected to draw on knowledge from the answers to originating questions.

The corresponding questions are:

Q_0: Why is diabetes a challenge for school and society?

Q_1: What is diabetes?

$Q_{1,1}$: What are the consequences of diabetes?

$Q_{1,2}$: What is the cause(s) of diabetes?

$Q_{1,2,1}$: How has knowledge of the cause(s) of diabetes changed over time?

$Q_{1,2,2}$: How are possible causes identified?

Q_2: How to describe and investigate the distribution of diabetes?

$Q_{2,1}$: Who is afflicted with diabetes? (Where do they live (geographic distribution), how old are they, age-distribution, socio-economic distribution etc.)

$Q_{2,2}$: How many is afflicted with diabetes? (Distribution in time)

Q_3: What is written about diabetes in school texts? (Curriculum, textbooks, etc.)

Q_4: How are known school lessons on diabetes? (E.g. in published lesson studies)

Q_5: Why choose the theme "diabetes"? Why should it be a concern for schools?

$Q_{5,1}$: What do pupils know about diabetes? What are their experiences? Will diabetes be a motivating theme?

Q_6: What could be suitable settings or scenarios wherein to learn about diabetes?

The sub-questions put forward here are clearly generated by us as educators representing two different disciplines, and while we clearly foresaw how Q_0 could be attacked from within each of our disciplines, we found it harder to identify connections between the disciplinary branches of the tree structure. Only for Q_2, we were able to justify a connection, as it is instrumental to answering $Q_{1,2,2}$, since statistical methods are invaluable in diabetes research. More connections could be envisaged to, and within, the didactic branch. In particular, answers to Q_3 would inevitably shed light on Q_2 and $Q_{1,2}$ through study of media intended for lower secondary school. Conversely $Q_{1,2}$ would enable a critical stance towards the scrutinized media in Q_3, while Q_3 would further aid the inquiry into Q_5 and Q_6. Finally $Q_{5,1}$ nearly begs interaction with pupils (e.g. interviews) which would be greatly beneficial to answering Q_6.

The a priori analysis could be continued into even more detailed questions, and is perhaps never ending. The possible connections between branches could be argued to be even more numerous than indicated here, but the analysis serves mainly to prepare us for the upcoming lessons with the students, trying to identify the most likely student questions, answers and difficulties, that could arise within the time available. While the a priori analysis thus support our preparation, helping us identify what kind of knowledge can be developed in a SRP generated by Q_0, it also entails a risk: That we use our findings, especially our own answers in normative or prescriptive ways, while directing the students' work. But in a realised SRP, the generating question and the deliberations of the study community (the class) has to be the authority deciding the direction of the SRP. Bosch and Winsløw (2015) highlights this fundamental challenge to manage SRPs and criticize how this is usually circumvented in school contexts:

> "The decision of when to stop or pursue the study, which is closely related to the inquirers' consideration of what is an acceptable answer and what is not, appears as another important problem in the managing of research and study paths, a problem which is often minimised in the school context by means of the didactic contract: "a solution is acceptable when the teacher considers it to be so" (Bosch & Winsløw, 2015).

There seems to be a potential conflict here: Self-sustained inquiry processes should be allowed to go where the inquirers decide, but inside education pre-set things (works) are to be learnt. Is it possible to reconcile investigative freedom and tight guidance?

We believe it can be done by employing two new pieces of didactic infrastructure. The first is '*selective picking'* which put the teacher into a subtle control position in the study community. *Selective picking* is inspired by a very common structure of teaching in Japan, involving first a session where the pupils work at a problem independently, while the teacher moves around observing and taking note of pupil work especially interesting and relevant for the progression of the lesson (Kikan-Shido phase). Then, the work of these pupils is brought forward in a whole class discussion (Neriage phase) (See e.g. Shimizu, 1999). This practice was also pursued in the case, as we shall see in the next paragraph.

The other didactic infrastructure is *'control questions' or 'side questions'*, an idea coined by Yves Chevallard:

> Any question Q can indeed be supplemented meaningfully by one or a series of "side questions" Q* that will be touchstones for controlling the quality, thoroughness and profundity of an inquiry into question Q. It is in this way that it becomes possible to point out meaningfully—and not out of sheer pretentiousness—the utility of such and such work O to get deeper into the question studied (Chevallard, 2012)

The exact nature of such control or side questions is, to our knowledge, not systematically explored. We would like to remark that we prefer the term 'side question' as "control questions" carries strong connotations to overt teacher control, which we believe runs contrary to the aim of self-sustained study and research processes. On the basis of our case, the final section contains some suggestions as to the quality and function of *side questions*, in order for them to act as a steering device, without taking away the desired autonomy of SRPs.

Guiding and monitoring the SRP.

The case SRP was planned for a student workload of approximately 40 hours, with 16 hours being set aside for whole class teaching, and the rest to student's individual work. The SRP was experimented with 14 students over the course of 4 weeks in the spring semester of 2015. A script was prepared for the succession of lessons and individual work periods. The overall setup was divided into four stages: First a preparatory stage: A one lesson introduction to the work structure and a first generation of sub-questions from the initial question. Then three main stages: five lessons in one day, spaced one week apart, with the individual work to be done in between. Between the preparatory stage and the first main stage the students carried out individual media search. The first main stage began with a *conference* based on a tree-diagram rendition of the student generated sub-questions (See also Figure 2 below). Just as in Barquero et al. (2007), *conferences* were used as a means for the class (the study community) to clarify which avenues of inquiry they would first pursue. Each individual student was at this point given complete autonomy in his or her choices; no indication of preferred direction was disclosed by either educator. Five small groups were formed, based on agreements to investigate common questions in the subsequent more research oriented part of the lessons. In the final hour of the day, another conference were held where each group shortly presented the results of their investigations and stated what study of media they would undertake until the next main stage. The day ended with a session where each student individually wrote a note specifying an issue relating to the inquiry of the day, which he or she would like the educators to elaborate on in the course of main stage two. These notes were collected by the educators and carefully reviewed immediately after class. This is the crux of the 'selective picking': from the fourteen written issues, we picked one each, that we deemed most promising, in the sense that a presentation based on the particular issue would connect well with the curricula for the whole module. By this choice, we could indicate a direction and make it easier for the students to carry on their investigations in that direction with greater depth and profundity.

Main stage two consisted of a session dedicated to formulate questions to an invited 'resource person', in this case a person who had lived with diabetes all through her school years. This presentation and discussion session was followed by the two educators' presentations, and subsequently the first conference of the day. The conference debated the way forward in light of the three presentations. A sort of consensus among the groups of students was reached as to what *research* would be undertaken in next couple of hours. At the end of this stage came the final conference of the day, and the second and final round of writing down issues for "selective picking".

Main stage three commenced with the educator presentations followed by a short conference to determine the direction of inquiry for each small group of students. At the end of the day a final session was held with the purpose of drawing a "tree" of questions and answers reflecting the knowledge obtained by the study community as a whole. This served to bring a sense of closure even though the path could carry on, and also highlighting the individual study and research paths' relation to answering the initial question Q_0.

In order to monitor, and to document for research purposes, the progress along the path, each student was asked to keep a sort of electronic diary. This is quite simply a document in which the student writes down what media had been consulted, what notes were taken, what conclusions had been drawn, what calculations had been made etc. - in short, all the messy scribblings that anyway arise in the course of an inquiry process. No special format was required, except that it had to be consecutively recorded and nothing erased.

Realised SRPs

As mentioned above, the very first conference was focused on students' derived questions, formulated in view of answering Q_0. The questions were compiled into a tree-structure and discussed with the students (Figure 2). As we can see, it is a much larger arborescence than our own a priori analysis.

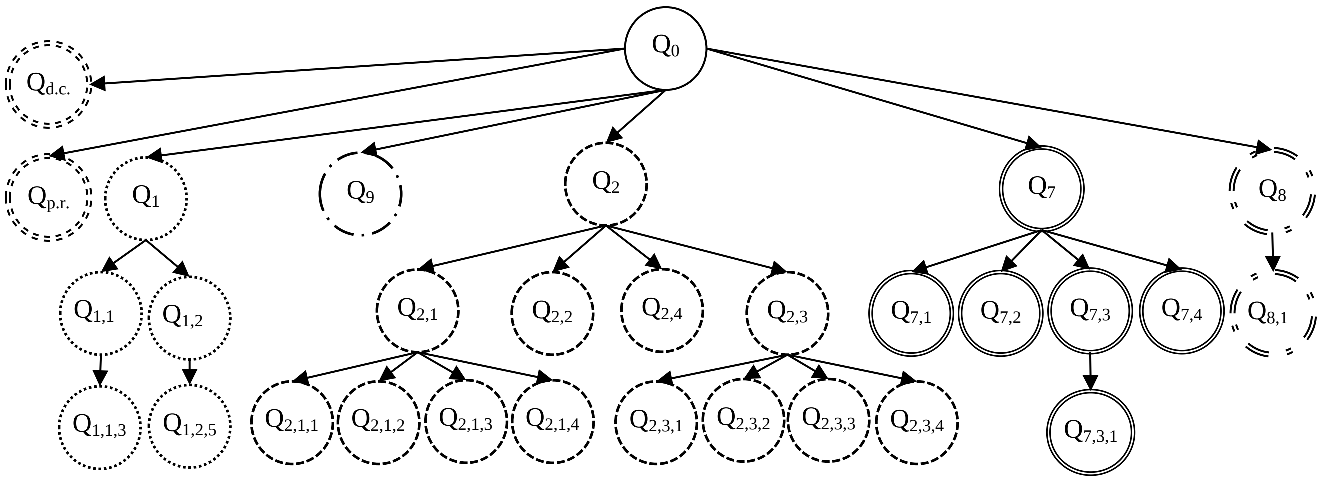


Figure 2: A posteriori analyses of derived sub-questions for the study community as a whole.

Q_0:	Why is diabetes a challenge for school and society?
Q_1:	What is diabetes?
$Q_{1,1}$:	What are the consequences of diabetes? (What does it entail for the individual to be afflicted by diabetes?)
$Q_{1,1,3}$:	Which sequelae does diabetes entail?
$Q_{1,2}$:	What is the cause(s) of diabetes? (What factors influence the development of diabetes?)
$Q_{1,2,5}$:	What is the difference between type 1 and type 2 diabetes?
Q_2:	How to describe and investigate the distribution of diabetes? (What does statistics say about diabetes regarding age, diet, genetics and mortality?
$Q_{2,1}$:	Who is afflicted with diabetes? (Where do they live (geographic distribution), how old are they, age-distribution, socio-economic distribution etc.)
$Q_{2,1,1}$:	What age group is typically afflicted by the illness?
$Q_{2,1,2}$:	How many school-teachers are diabetics?
$Q_{2,1,3}$:	Does diabetics have more sick leave?
$Q_{2,1,4}$:	Does diabetics suffer greater unemployment
$Q_{2,2}$:	How many are afflicted with diabetes? (Distribution in time)

$Q_{2,3}$: How to describe diabetes as an economic challenge?

$Q_{2,3,1}$: What does the average diabetic cost society?

$Q_{2,3,2}$: How many money does the country spend on diabetes research subsidy?

$Q_{2,3,3}$: How many money does the country spend on diabetes medicine subsidy?

$Q_{2,3,4}$: Is more focus on prevention economically preferable, or is treatment of developed cases cheaper?

$Q_{2,4}$: What is the distribution between type 1 and type 2 diabetes?

$Q_{2,4,1}$: Which type is the most expensive for society?

Q_7: What role does school play in pupils' diabetes?

$Q_{7,1}$: What fosters diabetes – and do we have to inform about it in school?

$Q_{7,2}$: Does pupils with diabetes have special social challenges?

$Q_{7,3}$: Is special considerations to be taken if a pupil has diabetes?

$Q_{7,3,1}$: What about pupils with fear of needles?

$Q_{7,4}$: How substantial knowledge must a teacher have of diabetes, if a pupils is afflicted with diabetes?

Q_8: What consequences does it have for teaching that some pupils have diabetes?

$Q_{8,1}$: Is diabetes a contributory cause of pupils having difficulty concentrating?

Q_9: Is there a relationship between diabetes and obesity?

$Q_{d.c.}$: How is diabetes connected to health? Who decides if diabetes is a challenge at all? Why ask about the reasons for the challenge instead of how to solve it?

$Q_{p.r.}$: What can the individual person do to avoid diabetes?

We notice that questions of didactic nature (Q_3-Q_6) are not present, instead a number of questions related to general social and pedagogical challenges of being a teacher are raised (Q_7). Although Q_8 concerns teaching, is does not seem to be specific to diabetes as a topic for teaching. The disciplinary oriented question strings (Q_1 and Q_2) are clearly present, with the mathematical one being the most strongly elaborated. Q_9 springs directly from Q_0 and while it is very specific, it lends itself equally well to be answered from the perspective of each discipline. Then there are two residual groups of questions: $Q_{d.c.}$ question the didactic setup of the SRP, and could be seen as a metadidactic resistance to the change in *didactical contract* (signified by the subscript 'd.c.') (Brousseau, 1997). $Q_{p.r.}$ represents questions which deal with health information and a *personal responsibility* (signified by subscript 'p.r.') of citizens to avoid becoming a victim of diabetes. These are mostly connected to social dynamics and moral education, and are as such valid for the answering of Q_0, but only marginally justifiable endeavours within the frame of the case course.

Ten of the fourteen students managed to participate in all phases of the SRP. And their diaries have all been analysed carefully. The realised paths can be divided in three groups, and in the following I present one path from each. The first group (four paths, student D, H, PP, and MB) is characterised by not showing any investigation of didactic questions. Instead they exhibit a disciplinary inquiry into both statistical and medical questions related to diabetes (see e.g. Figure 3).

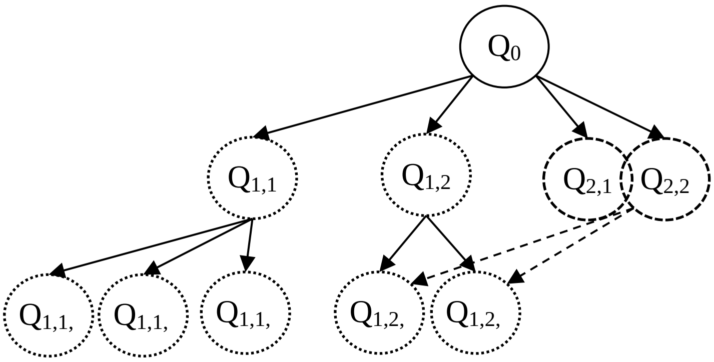


Figure 3: A posteriori analysis of realized SRP for student D.

Q_0:	Why is diabetes a challenge for school and society?
$Q_{1,1}$:	What are the consequences of diabetes? (What does it entail for the individual to be afflicted by diabetes?)
$Q_{1,1,1}$:	How often do you need to see a doctor?
$Q_{1,1,2}$:	What about money for medicine?
$Q_{1,1,3}$:	Which sequelae does diabetes entail?
$Q_{1,2}$:	What is the cause(s) of diabetes? (Is Danish lifestyle directly related to diabetes?)
$Q_{1,2,3}$:	Is lack of physical activity a cause for the increase in diabetics?)
$Q_{1,2,4}$:	Is unhealthy diet a cause for the increase in diabetics?
$Q_{2,1}$:	Who is afflicted with diabetes? (How old are they, age-distribution)
$Q_{2,2}$:	How many are afflicted with diabetes? (Is the increase in diabetics just a consequence of better diagnostics?)

There is generally a slightly greater emphasis on the biological questions, but often backed up by mathematical knowledge and connections among the disciplines are discernible. In the case of Student D (Figure 13), where the disciplinary interaction is the most explicit, questions $Q_{2,1}$ and $Q_{2,2}$ are answered statistically in an intertwined fashion and the answers are used to draw conclusions about possible biological cause and effect. (Dashed arrow to $Q_{1,2,3}$ and $Q_{1,2,4}$) $Q_{1,2,4}$ has relation to Q_9 but is more general. It could be argued that Q_9 is here indirectly answered using mathematical knowledge.

The second group (three paths, student C, K and PGK) considers mainly biological questions, making next to no reference to mathematical knowledge, and deal mainly with possible consequences for the work as a teacher by having diabetics in the classroom.

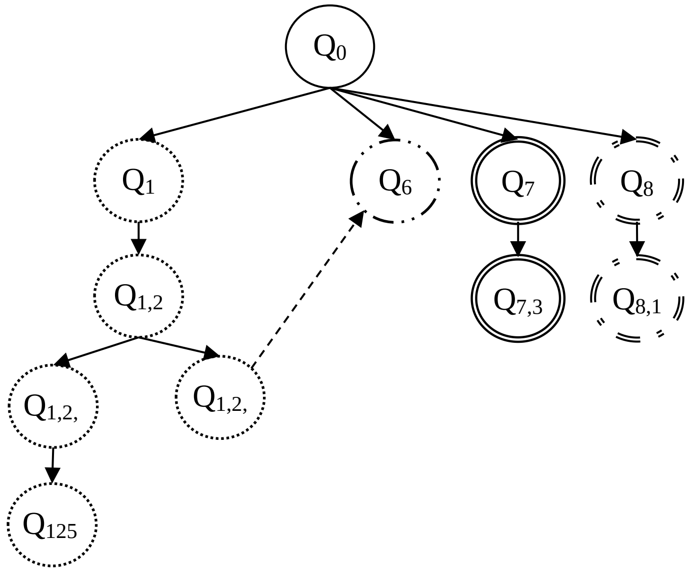


Figure 4: A posteriori analysis of realized SRP for student C

Q_0: Why is diabetes a challenge for school and society?

Q_1: What is diabetes?

$Q_{1,2}$: What is the cause(s) of diabetes? (What factors influence the development of diabetes?)

$Q_{1,2,5}$: What is the difference between type 1 and type 2?

Q_{1251}: What other types of diabetes exist?

$Q_{1,2,6}$: How does insulin function in the healthy body?

Q_6: What could be suitable settings or scenarios wherein to learn about diabetes?

Q_7: What role does school play in pupils’ diabetes?

$Q_{7,3}$: Is special considerations to be taken if a pupil has diabetes?

Q_8: What consequences does it have for teaching that some pupils have diabetes?

$Q_{8,1}$: Is diabetes a contributory cause of pupils having difficulty concentrating?

In the specific case of Student C (Figure 4), mathematics is mentioned only as notes to the educator presentations, and there is a suggestion to *inform* pupils about diabetes on the basis of statistical information regarding which population groups have the greater risk. However when the aim is inquiry rather than ‘just’ informing, the knowledge base it taken from biology. For instance, it is suggested that learning about ‘insulin mode of action’ could be the way didactic trajectory towards learning about diabetes. Thus there is a tenuous connection from $Q_{1,2,6}$ to Q_6.

The third group (three paths, student M, L and MLN) is characterised by not considering didactic questions at all, and staying nearly exclusively within one of the disciplines.

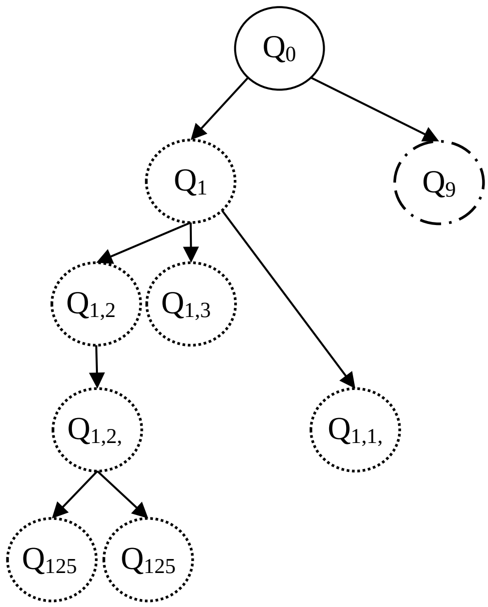


Figure 5: A posteriori analysis of realized SRP for student M

Q_0: Why is diabetes a challenge for school and society?

Q_1: What is diabetes?

$Q_{1,1,3}$: Which sequelae does diabetes entail?

$Q_{1,2}$: What is the cause(s) of diabetes? (What factors influence the development of diabetes?)

$Q_{1,2,5}$: What is the difference between type 1 and type 2?

Q_{1251}: What other types of diabetes exist?

Q_{1252}: Is diabetes hereditary? How do genes predispose for diabetes?

Q_9: Is there a relationship between diabetes and obesity?

Student M (Figure 5) is a representative of the third group and is the only one to consider hereditary aspects of diabetes (Q_{1252}). In fact, the genetic aspect of diabetes is used by Student M in answering most questions in the biology branch. However, Q_9 is not dealt with using genetics as a common mode of explanation of relationships between diabetes and obesity, but it is nevertheless pursued within the frame of school biology. Notice the contrast to Student D where mathematics was employed.

Selectively picked issues and their influence on student SRP

In this section we take a closer look on the issues proposed by the students, those picked by us as educators, our presentations based on them, and their traces as they appear in the student logs. The first round of formulating issues was marred by confusion, as the students were obviously not used to being given this responsibility. Only three issues came to our attention: How is insulin produced in the healthy body? What happens ”biologically”? Do diabetics die earlier than others? Thus there was not much selective picking possible. We opted to do two presentations dealing with all three proposed issues to emphasize the student ownership and responsibility for the study process. We also made a point of mentioning which students had proposed the questions. One (standard transmissive) presentation handled the first two issues from the perspective of the biology discipline, focussing on the physiological processes of insulin production and Type 1 diabetes. The other exemplified a statistical inquiry of the third issue presented as a written succession of questions and answers, while explicitly demonstrating the dialectic between the study of media, and construction and research in a milieu.

The second round, significantly more successful, produced twelve issues from which we choose: “Diet and exercise in relation to improve life with type 2 diabetes” and “Help me understand the statistics in the research paper: *A common Greenlandic TBC1D4 variant confers muscle insulin resistance and type 2 diabetes*” (Moltke et al., 2014). The former was dealt with in a presentation taking statistical findings as the point of departure, then moving into biological explanations for the observed statistical correlations between diet and exercise. This was done in a fashion which again emphasised the succession of questions and answers. The presentation based on the second issue concerning the research paper was standard transmissive, giving explanations of how to calculate and interpret p-values as presented in the paper. In should be noted here that the paper which the question refers to was found independently and used by Student M as she studied Q_{1252}.

The teacher presentations of the two selected issues are indeed referenced in the student notes/logs. However it is not abundantly evident that the students took the material to heart, in the sense that it had a clear influence on their paths. For instance, it was our hope that student M would have deviated from the “pure biology” path as a consequence of being exposed to an explanation of the statistics in the research paper. We also hoped that by focussing on these aspects, other students would have been encouraged to delve deeper into the genetic and statistical research surrounding diabetes. In general there were fewer results of this in terms of statistical inquiry, than in terms of biological ones. For instance, Student C concluded in her log from the first round of issues that diabetics statistically die ten year earlier than non-diabetics, but this did not prompt her to do further statistical investigations, instead she sought out biological explanations for this statistical fact, as she expanded her answer of $Q_{1,1,3}$. From the viewpoint of school mathematics this is perhaps less satisfactory, but in the interdisciplinary setting we believe it shows a quite common challenge to overcome the perception that statistical analysis is somehow mere technical afterthoughts, while in fact the statistical interpretation may be crucial to produce meaningful and precise interpretations of data,

We acknowledge that we cannot definitively conclude from this short SRP trial whether "selective picking of student raised issues" will be an important piece of didactic infrastructure to guide the study process. Nevertheless it did serve an institutional need for a space accommodating "visits" of mandatory curricular works that were timely in the sense of following the direction of the SRP, and thus making the works less decoupled from questions they provide answers to. We would also like to emphasize that "selective picking" is not a didactic infrastructure which can radically and automatically change the direction of the study process.

We would have liked the students to venture more into diabetes as a topic for teaching, but none of the student proposed issues pointed in that direction, making us unable to emphasise this line of inquiry. There has to be at least one student who identified the need. At the very end of her log, Student H, who had made a thoroughly bi-disciplinary inquiry, lamented her missing path into the didactic branch: "…with all I have investigated myself and what the others have shared, I am left with a lack of knowledge about how I am going to teach diabetes in school". The fact that others had looked into didactic questions came to her attention only during the very last conference. Another round of posing issues to be selected for educator presentation could have drawn attention to this, at a time when the students were disciplinarily prepared for the study of didactic questions. We thus hypothesize that *conferences* and the *selective picking*, in conjunction with a larger time frame than we had, could constitute a viable didactic infrastructure of SRPs in this setting.

Discussion

The qualities of students' answers are not evident from the tree diagrams, and the depth or superficiality of their inquiry is not assessed in this paper. We have looked for didactic infrastructure to guide self-sustained study and research with an interdisciplinary nature. I have only analysed what can be seen from the logs, even though obviously more happened than what is written there. After the SRP, the students were asked to participate in an evaluation of their experience. An interesting point was that all of them indicated that they found the duration too long and demanding, in terms of having to keep themselves going in the exploration of questions.

Having or acquiring a Herbartian attitude is obviously strenuous. The change of didactic contract is mentally exhausting, and may only succeed through continued exposure. It is a fact from the analysis of the individual paths that the students only managed to deal with a maximum of two branches of the envisioned path, which suggests that the duration of the SRP should have been somewhat longer, contrary to the opinion of the students themselves.

Making these ends meet may require a more deliberate use of *side questions* as introduced above. We propose that such questions should be very concrete and deeply specific, such as: How to calculate and interpret the test-statistic for odds ratio-test? What is the biological mechanism for glucose transport in fat cells? What does school textbook X say about obesity? - introducing “study and research activities” which, as much as possible, deepen the questions identified by students. Evidently, this last desideratum implies a difficulty: How to avoid that students are given such questions without going through a path that motivates them? Clearly, one should avoid that side questions simply make students and educators return to visiting monuments, concealed as monumental questions with no reason for the asking. To avoid this predicament we consider that side questions, as exemplified above, could be used for two separate purposes: going *deeper* in the path, or going *wider*. In order to go deep, we consider that timing is essential. Side questions should not be stated early on in the SRP, rather they should be posed to students when they are well under way, but need a little push going to the depth which the curriculum, or the educator, expects them to. Using side questions to go wider needs to be expanding from the *topics* which has already to some extent been conquered by the study community (or possibly a part of it); using side questions to try to make the students jump to another branch of the SRP would seem futile.

Concluding remarks

In this paper I have presented our design and evaluation of a study and research path as *a priori* and *a posteriori* analysis respectively. It was seen in the *a posteriori* analysis that students paths fell into three categories, where all pursued at most two branches of the envisaged path: Biology and mathematics interaction, Biology and didactics interaction, and finally biology or mathematics separately. In order to monitor the students’ progression along the path, we have employed the use of written *diaries,* which were handed in after each of the three main phases. Likewise, *conferences* have been part of the didactic infrastructure to decide on the study community’s direction along the path. Most importantly, students have been asked to *pose issues* critical to their investigation as suggestion for presentation by the educators. Among these issues we have *selectively picked* the ones we judged would lead the path in desirable directions. We have seen that uptake from these presentations were traceable in the diaries, more so for presentations related to biology than to statistics, and also towards structuring the diary as a conscious progression between questions and answers. The guiding function of “selective picking” was thus only partially successful, but promising for the subtle control of the direction in study and research processes while maintaining significant student autonomy. As a more fast-acting didactic infrastructure, we have discussed the possible quality and appropriateness of *side questions* proposed by Yves Chevallard, and found them suitable to attain greater depth of study, while we remain wary of their fitness to guide students towards other directions in their study and research path.

Acknowledgements

I would like to extend my profound gratitude to Henrik Levinsen for many interesting discussions during the planning and implementation of “Health – risk or chance?” Kjeld Poulsen provided valuable insight into the statistical research around diabetes and Carl Winsløw were as always a great source of inspiration and valuable comments.

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