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## **PhD thesis**

Ane von der Fehr

# **Exploring social networks of science education actors in Danish Science Municipalities**

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

Academic supervisor: Jan Sølberg  
Industrial supervisor: Hans Colind Hansen

Submitted: April 21<sup>st</sup>. 2016

Name of department: Department of Science Education

Institutnavn: Institut for Naturfagenes Didaktik

Author: Ane von der Fehr

Title of thesis: Exploring social networks of science education actors in Danish Science Municipalities

Afhandlingens titel: Et studie af sociale netværk bestående af aktører på naturfagsområdet i danske Science-kommuner

Subject description: Science education research focusing on the municipal level.

Submitted: April 21<sup>st</sup>. 2016

Academic supervisor: Jan Sølberg

Industrial supervisor: Hans Colind Hansen

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## Acknowledgements

I feel privileged that I have had the opportunity to be part of two very different organisations and cultures in my appointment as industrial PhD student. Being appointed in Astra enabled me to experience a community of committed colleagues continuously striving towards improving and developing efforts aimed at science education. The affiliation to Department of Science Education became my open sesame to abundant knowledge in the community of many dedicated researchers in the department. By being the link between these two communities seemed to be a sweet spot. I want to thank my colleagues for bringing me the best of two worlds. Especially my supervisors deserve my deepest gratitude: Jan Sølberg and Hans Colind Hansen, you have been second to none. Somehow you have managed to help me find my way in all the phases of the project, and time and time again I have left our meetings feeling even more inspired and eager to continue the research. It has been the greatest pleasure to work with you. I also want to acknowledge the kind assistance offered by my colleague, Jesper Bruun, when I most needed a guide into the world of social networks.

The project led me to a three-months stay in Japan. I owe my heartfelt thanks to Professor Ogawa and his students in Ogawa Lab at Tokyo University of Science. This stay changed my perspectives for always.

I highly appreciate the many respondents in the Science Municipalities who were engaged in the study. It has been a great opportunity to be invited in to their worldviews and a pleasure to experience these dedicated actors working to develop science education.

At last I want to thank my closest colleagues and private alters for bearing with me and providing the backing that I needed on this journey.

## Prologue

This prologue serves as the ‘what, why, and how’, which formed the exploration of science education development in the current research project. Each element presented here will be discussed in detail in the thesis, but they are introduced in short to facilitate readers’ induction to the field of research and the premises it entails.

Focus on educational development has evolved from considering schools isolated to a broader view recognising the influence of contextual factors in school districts (Reynolds et al., 2014) (further discussed in Chapter 2). As a result, the importance of a wider group of actors has been acknowledged. This perspective includes not only teachers and school leaders, but also actors outside the immediate school community such as administrators, Local Education Authority advisors (LEA advisors), and politicians (reviewed in McLaughlin & Talbert, 2006). One educational effort aiming at this broader target group was the Danish *Science Municipality Project (2008-2011)* (the SM project), which served as context for the current research project.

The SM project engaged 25 municipalities (so-called *Science Municipalities*) with the objective “to establish links between the different stakeholders involved in science education in order to benefit from the collected resources in the field of science education in each municipality”<sup>1</sup>. Many actors affiliated to different organisations and hierarchical levels in the municipalities were each in their own way involved in developing science education. Results from TIMSS (2011) showed that students from schools in Science Municipalities performed better than other students in both math and Science/Technology (Allerup, 2012, p. 75). This also called for a further exploration.

The SM project was evaluated over the three-year project period. The results indicated that apart from political foundation, a coordinated effort involving interplay between relevant and important actors within the municipalities had strong influence on development of science education. In order to explore the development, it was necessary to understand the underlying social dynamics and mechanisms in the Science Municipalities. The main challenge was to approach this systematically, when interactions between so many and diverse actors were involved. This diversity thus complicated the task of generating an overview of the actors and the relationships connecting them. To deal with this complexity, it was relevant to consider the interactions between actors in Science Municipalities as social networks.

The concept of ‘networks’ is used among teachers, educational administrators and politicians, but there seems to be differing notions of the concept (Carmichael, Fox, McCormick, Procter, & Honour, 2006) (further discussion of the network concept in Chapter 3). Social networks can be used as a generic term for sets of actors who have relationships to each other (Marin & Wellman, 2011). In order to investigate how the social networks in Science Municipalities affected development of science education, I needed to explore these networks in detail. Therefore, I chose to approach the issue using Social Network Analysis (SNA), which offers a method to identify and analyse relationships between actors (Wasserman & Faust, 1994) (introduction to SNA in Chapter 3).

SNA can be used to explore relationships between actors in social networks that are bounded by affiliation to certain institutions, e.g. students in a class, teachers in a school, employees in a department, etc. But SNA also offers a means to identify actors who are connected in more undefined social networks constituted by certain activities, e.g. drug users and terrorists. In such ‘hidden’ social networks it is not possible to identify the actors a priori, because one can not immediately access a comprehensive overview of all the actors included in the networks. This was

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<sup>1</sup> <http://danishsciencefactory.dk/science-municipality-project>, retrieved January 21<sup>st</sup>. 2016.

the case in the Science Municipalities, where the 'activity' that connected the actors in social networks was their involvement in science education development (and not a common organisational affiliation as in bounded social networks). As will be clear in this thesis, the social networks in Science Municipalities were therefore complex entities of diverse actors who were connected based on their differing engagement in science education development, e.g. in developing science teaching; preparing municipal science education strategies; ensuring political support; establishing collaboration between formal and informal learning environments or enterprises, etc. (Sølberg & Jensen, 2011). Such activities seemed to involve actors across disciplines, institutions, administrations and hierarchical levels in the municipalities, which complicated the task of generating an overview of the actors connected in the social networks. In cases like this, respondent-driven SNA sampling methods can be used to map such social networks by pursuing the relationships that actors, who are known to be included, have to other actors in the given network.

In the current study, a respondent-driven SNA method called *snowball sampling* was chosen as a means to map the indistinct social networks in four Science Municipalities. Snowball sampling was a necessary tool to identify the many actors and their relationships, but it also entailed several potential issues regarding sampling, response handling, and data validity (discussed in Chapter 4 and Paper 2). By taking measures to address such issues, it was possible to map the social networks and to explore different characteristics of the network and the position of individual actors.

In order to achieve a further understanding of the importance of these social networks in science education, I needed to approach the concept of science education development (Chapter 2). This remains a multi-factored concept difficult to define and measure reliably. The primary objective for such development is improved science teaching and ultimately student learning. Science education is affected by multiple factors both directly and indirectly related to teaching (e.g. teacher professional development, availability of teaching materials and facilities, school leadership; science education cultures, etc.). Because of this complexity, individual quantitative measures, as e.g. student performance, allocated funding, and recruitment are available but not reliable measures of development. To elaborate on these examples, student performance can be measured from large samplings while the reliability of data can be questioned, because it requires an alignment between tests and teaching objectives to ensure that the results reflect students' learning reliably. Measures for funding allocated to development of science teaching requires access to the municipal administrations' accounts. If access was allowed, it would not be a straight forward task to sort out the funding used specifically for science teaching since some educational efforts are interdisciplinary and involves multiple subjects. At the same time, there can be national efforts that do not appear in the municipal accounts but which aim to improve science education in the municipalities as well. In addition, a correlation between funding and development of science education, would build on the assumption that increased funding leads to improved teaching. The verity of this assumption depends on the ways in which funding is used in practice. Turning now to the last of the measures, recruitment of students to science education, can be accessed, but students' educational choices are affected by many factors (Holmegaard, 2012), that are not all related to their experience of teaching quality. In addition, it requires a period of ten years to explore whether an educational effort in schools affects student recruitment. This approach was tested to explore the impact of a Danish school development project (Science Team K project – STK project) that focused on science education. Ten years after the STK intervention, the initiative seemed to have had no effect on recruitment of student to science educations (nor on student performance) (DEA, 2014). Even if any relevant quantitative measure were used tentatively as indicator of development, the dynamic nature of the social networks (see Paper 2) would impede reasonable comparisons or interpretations of correlations between aspects of development and characteristics on individual as

well as on network level. These limitations emphasise the complexity in tracking effects of educational efforts. Therefore, using approximated quantitative measures as indicators of development of science education (either individually or taken as a sum), would not be a reliable gauge, but would rather present an oversimplified notion of science education development. Such an approach would not contribute to explaining the potential of social networks in position to facilitate science education efforts in municipalities, which was my interest in this research project. Nor would it explain how this ultimately affected the quality of teaching. Therefore, I found it more useful to use descriptive measures to try to understand the mechanisms involved in development rather than trying to quantify the effect of mechanisms in the social networks in relation to science education development. To this end, mobilisation of resources was taken as a fundamental gauge for a number of pathways ultimately leading to improved teaching and learning in science (further discussed in Chapter 2). Overall, mobilisation of resources is enabled through relationships among actors. Therefore it was relevant to explore how resource mobilisation occurred as a consequence of the interactions in social networks of actors involved in development of science education in Science Municipalities. This was explored in the current project with a focus on the central actors in the social networks. This investigation offers a contribution to the field of research in science education development.

# 1 Introduction

## 1.1 Abstract

Science education development is a field of many interests and a key interest is recruitment of students who wish to pursue an education in science. This is an urgent societal demand in Denmark as well as internationally, since highly skilled science graduates are needed for the continuous development in the science and technology industry. Therefore, much effort has been invested to improve science education. The importance of school external actors in development of education has been increasingly emphasised, also in the field of science education. This has led to a growing focus on how conditions and structures in municipalities affect the development. Projects aiming at the municipal arena have thus been initiated and the Danish Science Municipality Project (SM project) was such a project. Part of the objective in the SM project was to connect different actors involved in municipal science education development. The social networks comprised of these actors and the relationships connecting them (the so-called municipal science education networks (MSE networks)) were identified as important for development of science education in the SM project. Therefore, it was a key interest to explore these social networks in order to investigate how the central actors affected development of science education. By use of social network analysis (SNA), four MSE networks were approached empirically, and the actors and the relationships connecting them were mapped. The central actors were identified based on quantitative network data. Through qualitative interviews it was possible to explore how they affected the development. The analysis showed that their positions in the MSE networks enabled them to mobilise resources for use in science education development. This insight highlights the potentials embedded in MSE networks and the importance of supporting central actors to enable mobilisation of resources in these social networks in order to facilitate development of science education in municipalities.

## 1.2 Dansk resumé

Udvikling af naturfagsområdet er et stort interesseområde, og en vigtig del er rekruttering af studerende, som ønsker at tage en naturvidenskabelig uddannelse. Dette er et presserende samfundsmæssigt behov i Danmark, såvel som internationalt, fordi der er brug for veluddannede naturfagskandidater i den fortsatte udvikling inden for den naturvidenskabelige og teknologiske industri. Derfor er der blevet investeret meget i forbedring af naturfaglig uddannelse. Vigtigheden af skole-eksterne aktører i uddannelsesudvikling er blevet understreget i stadig større udstrækning, også inden for naturfagsområdet. Dette har ført til en øget opmærksomhed omkring hvordan kommunale forhold og strukturer påvirker udviklingen. Der er derfor blevet iværksat projekter, som er rettet mod den kommunale arena - heriblandt det danske Science-kommune-projekt (SK-projektet). Et formål i SK-projektet var at skabe forbindelser mellem forskellige aktører involveret i udvikling af naturfagsområdet i kommuner. De sociale netværk bestående af disse aktører og relationerne mellem dem (såkaldte kommunale naturfagsnetværk) blev identificeret som vigtige for udvikling af naturfagsområdet i SK-projektet. Derfor var det særligt interessant at undersøge disse netværk, for at udforske hvordan de centrale aktører påvirkede udvikling af naturfagsområdet. Ved brug af social netværksanalyse (SNA) blev fire kommunale naturfagsnetværk undersøgt empirisk, og de kommunale aktører og relationerne, som samlede dem, blev kortlagt. De centrale aktører blev identificeret baseret på kvantitative netværksdata. Igennem kvalitative interviews var det muligt at undersøge, hvordan de påvirkede udviklingen. Analysen viste, at deres position i de kommunale naturfagsnetværk gjorde dem i stand til at mobilisere ressourcer til brug i udvikling af naturfagsområdet. Denne indsigt understreger de potentialer, som er indlejret i kommunale naturfagsnetværk, samt vigtigheden af at understøtte centrale aktører og derved muliggøre

mobilisering af ressourcer i disse netværk for at facilitere udvikling af naturfagsområdet i kommuner.

### 1.3 Summary

This research project explores the social networks of actors involved in science education development in Science Municipalities involved in the Danish Science Municipality Project (SM project). Following research question guided the research: *How are central actors in social networks in Danish Science Municipalities affecting development of science education?*

The thesis comprises a synopsis and three papers. The first chapter in the synopsis describes the context for the research project. The municipal science education networks (MSE networks) that were explored existed in municipalities involved in the SM project, which focused on establishment of structures in municipalities to facilitate and maintain development of science education (e.g. science education boards, municipal science education coordinators, and science education strategies).

Chapter 2 serves as a short introduction to the complex concept of science education development and the interpretation of the concept in context of the current PhD project. The following two chapters address the applied theoretical and methodological framework by describing social network analysis (SNA) and its application in educational research as well as in the methodological design of this project.

This first part of the thesis serves as a basis for presenting the three papers outlined in Chapters 5, 6, and 7. Paper 1, *What can we learn from the Science Municipality project?* presents the main results from the three-year evaluation of the SM project. It serves to outline the background for the research conducted in the PhD project. The development that took place in the Science Municipalities is presented here based on quantitative and qualitative data. The focus in the paper is aimed at exploring five main elements in the SM project: MSE coordinators, science education boards, the MSE coordinators' relationships to different actors, political foundation, and science education strategies. The results from the SM project pointed to the importance of social networks of different actors involved in municipal development of science education (in the following called Municipal Science Education Networks (MSE networks)). This finding was the reason for exploring these social networks in detail, which is the aim in Paper 2.

Paper 2, *Validation of Networks derived from Snowball Sampling of Municipal Science Education Actors*, presents results from the validation study which was conducted following the mapping of MSE networks in four selected Science Municipalities. A respondent-driven SNA approach, termed *snowball sampling*, was used to collect quantitative network data to identify the actors in the MSE networks and map the relationships among them. Network representations were generated and the network data was validated through interviews with selected actors in the social networks. They were asked to recognise their own network position and overall structures in the network representations. It revealed that the network representations resulting from the snowball sampling aligned with the majority of the interviewed actors' perception of the MSE networks in question. This indicated that snowball sampling was an applicable approach to map such social networks in municipalities. The network data from the SNA study thus enabled identification and exploration of the central actors in the MSE networks. This was the focus in Paper 3.

Paper 3 presents an exploratory study of different aspects of centrality expressed in the MSE networks. The study focuses on three centrality measures: indegree, closeness, and betweenness centrality. The actors, who were most central (with respect to the selected centrality measures), were identified and interviewed in the following qualitative study. Based on characteristic of the centrality measures described in the literature, the central actors were asked if they recognised the functions associated with their central positions in the MSE networks. Through elaborating

questions it was possible to explore the functions of their centralities as they were expressed in the MSE networks. It showed that the positions of central actors enabled them to mobilise resources for use in science education development in different ways.

After the introduction of the three papers, Chapter 8 presents a discussion of the findings and implications from each paper. In addition, the research design and resulting consequences for the project are addressed and alternative approaches are discussed. As a perspective, the concept of social capital is presented in Chapter 9 as a metaphor for the advantage of MSE networks in science education.

The final chapter before the afterword presents the conclusion and suggests issues for future research. The results revealed that central actors in social networks in science municipalities mobilised resources defined by their network positions and thus contributed to the development of science education.

This emphasises the importance of supporting central actors in municipal social networks in order to mobilise resources for use in science education. Further investigation of content and quality of relationships in MSE networks is a relevant issue for future research, which could supplement insights achieved in this project.

## **1.4 Project context**

### **1.4.1 Researcher motivation**

When I applied for the industrial PhD position in Astra (formerly the National Centre for Science Education (NTS)), I was working as evaluator of the Science Municipality Project (SM project). This developmental project was led by Astra and aimed at developing science education in municipalities. The SM project period was about to end and the project leader from Astra, as well as the involved municipal actors were discussing what the future would bring after the project. What caught my attention and peaked my interest at that time was that they seemed to be concerned about whether the development would come to an end. To me it seemed so peculiar that they were perfectly aware that the efforts might come to nothing when the project period expired, but at the same time there did not seem to be easy ways to prevent this possible consequence of the project end. At that time, I was new in the field and was not yet acquainted with research about sustainability of efforts (e.g. Fullan, 2000)). I was blissful ignorant of the fragility after implementation, and unaware of the high percentage of projects that come to nothing after the formal end (as reviewed in Henriksen, Buhl, Misfeldt, & Hanghøj, 2011).

At the final conference for the SM project, the project leader used a picture to describe the concern about the future development. The picture showed a desert. A railway track emerged from the horizon. An old-fashioned steaming locomotive paved its way through the desert. The railway tracks reached all the way from the horizon to the foreground of the picture. Very abruptly the tracks were torn in front of the locomotive. The picture symbolised the journey for the municipal actors in the SM project. It made me think about how the project had served as organising structures for the science education development, just like the railway tracks had kept the locomotive on track. What was difficult for me to understand was how hard it was to ensure a continued development after the end of the project. I assumed that if it was possible to predict the worst case, it was possible to prevent it as well. This concern served as a stepping-stone in my application for the PhD position. I wanted to explore what was required to maintain science education development. In a wider sense, I aimed to explore what was needed to build new tracks in front of the locomotive. It was quite a goal to set, but also very motivating for the research I was about to start.

### 1.4.2 The industrial PhD programme

The current research project was enrolled in the industrial PhD programme and supported by Innovation Fund Denmark and the Lundbeck Foundation. Astra, which hosted the project, is an independent national centre within the public administration affiliated with the Ministry for Children, Education and Gender Equality<sup>2</sup>. Astra's mission is to be *'the coordinating and unifying actor strengthening science learning in Denmark'*<sup>3</sup>. My employers in Astra were therefore curious and eager to achieve evidence-based knowledge about the developmental processes they were facilitating in municipal projects. This was the motivation for Astra to engage in the industrial PhD programme. This also meant that Astra was not trying to affect the project in certain directions, neither methodologically nor regarding the research question guiding the process. Therefore, the framework for this project was wide and the only outline for the PhD position was that the candidate should explore the processes initiated in the SM project. I thus had a high degree of autonomy in the project. There were no established guidelines according to an appropriate research design for investigating this field. I felt a commitment and engagement to generate an insight, which was relevant and important both for municipal actors so as to facilitate development of science education; for Astra to improve their practice based on research; and for the science education research field.

The purpose of the industrial PhD programme is *'to carry out a research project where result are applied in an enterprise setting'*<sup>4</sup>. Because of the enterprise affiliation, industrial PhD projects have special focus on application of result in practice. Therefore, this has been a point of attention for my employer, my industrial supervisor and for me. Since I am currently the first and the only industrial PhD student in Astra, no other PhD projects has created a precedent as to how results from a research project can be shared and applied in practice in the organisation. It motivated me as a researcher that the research was carried out in an authentic setting and also that the result were to find application in practice. Hence, a following period is planned aimed at disseminating result and facilitating the application of results among relevant municipal actors and in the organisation of Astra. Dissemination is not sufficient for the results to affect practice, but it is the first step for application. Some of the results approve current practice and can be applied by confirming continuance of the effort but now based on empirical evidence. Other results emphasise important conditions for science education development and implementation of these results requires dialog with relevant actors in order to align the conditions with the reality in municipalities. In addition, implementation of selected results might be facilitated if they are included in municipal science education strategies – that is, if these strategies are implemented in practice.

### 1.4.3 The Science Municipality Project

Denmark is comprised of 98 municipalities, which are geographically distinct areas with their own local government. Municipalities thus provide a clear delimitation of administrative and geographical units. They vary in size and population density and belong to one of five national regions. The municipalities are obliged to follow the national laws and regulations, but they are responsible for schooling up to grade 10 both legally and fiscally. Municipalities can be regarded as complex organisations with local government in place to manage the different intra-organisational subunits, that being educational institutions, informal learning environments, local enterprises, etc. Though municipalities are subject to national educational regulation, they govern the implication of regulations into practice in schools. Since municipalities are responsible for schooling, the municipal setting is relevant to consider, when exploring educational development. Astra has been

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<sup>2</sup> <https://www.retsinformation.dk/forms/R0710.aspx?id=124588>, retrieved April 14<sup>th</sup> 2016.

<sup>3</sup> <http://astra.dk/strategiske-indsatser>, <http://astra.dk/eu>, retrieved April 14<sup>th</sup> 2016.

<sup>4</sup> <http://innovationsfonden.dk/en/application/erhvervsphd>, retrieved November 4<sup>th</sup> 2015.

involved in different developmental projects with the aim of developing science education. The project that preceded the SM project, was the Science Team K (STK project 2003-2006)<sup>5</sup>, which was funded by the Lundbeck Foundation. This project was a school development project and it aimed to increase the interest in science and technology among students in one Danish municipality (Sølberg, 2007, p. 61). The STK project was facilitated by a local project manager and a project leader from Astra. After the STK project ended, continued science education development suffered from the lack of a central coordinating actor with relationships with the administrative and political level in the municipality. The local project manager had no formalised relationship with the administrative and political level and when the STK project ended, she had no authority to maintain the initiatives developed during the project. The project leader from Astra used the experiences from the STK project in the organisation of the SM project (2008-2011)<sup>6</sup>, which was funded by the Ministry of Children and Education (now Ministry for Children, Education and Gender Equality) and had focus on the municipal level. 25 municipalities (so-called Science Municipalities) were involved on a voluntary basis in the SM project, which focused on establishment of structures in municipalities to facilitate and maintain development of science education. Based on experiences from the STK project, it was a requirement in the SM project that a municipal science education coordinator (MSE coordinator) was appointed as coordinating centre in each municipality. In addition, it was preferred that the MSE coordinator had some degree of affiliation with the administrative level in the municipality. The MSE coordinators were supposed to generate an overview of the science education initiatives in the municipality and in this way increase the utilisation of existing resources. The SM project also aimed to facilitate establishment of other supportive structures in the municipalities, e.g. science education boards, political support, formulation of science education strategies, and organised networks of teachers (see Chapter 3 for distinction of use of the network term). These structures aimed to support continuous development of science education in the municipalities. After two years, the SM project was not a strong brand in many of the Science Municipalities (Sølberg, 2010). The SM brand did not seem to be attached with a collective municipal identity in all municipalities, but there were examples where the brand was used deliberately to increase attention to the initiatives (Sølberg & Jensen, 2011). However, it seemed to have established a ground for interplay between different actors, and in the evaluation, the social networks of these different actors showed to be important for municipal development of science education. Therefore, it was relevant to explore these networks in detail and this became the focus in the current research project.

#### 1.4.4 Science Municipalities in the research project

The 25 Science Municipalities were monitored for three years using quantitative questionnaires and yearly interviews with MSE coordinators during the evaluation of the SM project (Sølberg, 2009, 2010; Sølberg & Jensen, 2011). This data served as the basis for selecting four Science Municipalities for further investigation in the current research project. The municipalities were selected to ensure variation regarding the social networks to be investigated. The municipalities were characterised by different municipal key figures (Table 1<sup>7</sup>, based on Table 1 in Paper 2), different background and different conditions for science education development.

Based on data from the SM project evaluation, the four municipalities are presented in brief in the following.

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<sup>5</sup> <http://danishsciencefactory.dk/science-team-k-2003-2006>, retrieved November 4<sup>th</sup> 2015.

<sup>6</sup> <http://danishsciencefactory.dk/science-municipality-project>, retrieved November 4<sup>th</sup> 2015.

<sup>7</sup> Permission was obtained to call the municipalities by name when presenting results from the study, yet I decided to use code names.

	Mun S	Mun I	Mun L	Mun U
<b>Municipal key figures:</b>				
Number of inhabitants in 2012 (in 1000)	83	61	49	41
Population density (inhabitants./sq. km) in 2012	392	506	80	622
Socio economic index in 2012 (lower is better)	0,81	1,08	1.09	0,97
Number of primary schools in 2012	21	10	17	8

**Table 1: Overview of selected municipal key figures in the four Science Municipalities in the study. This data was retrieved from the public databases from Ministry of Economic Affairs and the Interior ([www.noegletal.dk](http://www.noegletal.dk)) in August 2015. The figures are based on data from 2012, because the further exploration of the social networks in this study took place in 2012.**

### *Mun S*

Mun S was the one of the four municipalities with highest number of inhabitants and most primary schools as well. In Mun S, there was no long history of special engagement in developing science education and hence no strong political support. The MSE coordinator was not provided time or much funding and overview of science education initiatives in the municipality was about to be generated. There were few activities aimed at science education development. However, there seemed to be high degree of support from teachers and organised network of teachers had just been established by the end of the SM project.

### *Mun I*

Mun I was a seaport and known for different kinds of informal learning environments. The informal learning environments played an important role in schools, and science education development received strong political attention. The MSE coordinator was provided with funds and supported by a steering committee comprised of appointed teachers. A good overview of initiatives for development of science education was established in the municipality. Mun I had a strong focus on science education and there was support from a varied set of actors. In addition, a well-developed organised network of teachers was established in the municipality.

### *Mun L*

Mun L was a big municipality but had the lowest population density. It was an industrial town with pronounced industrial estates. The municipality had previously been engaged in a science education development project and the MSE coordinator was provided with time and funds. There was a well-developed organised network of teachers and a science education steering group had been established during the SM project.

### *Mun U*

Mun U was the smallest of the four municipalities, but had the highest population density. In recent history, science education had achieved high priority from the political level and resources were provided to support initiatives in science education. The SM Project was a natural extension of the existing agenda for science education in the municipality. The primary MSE coordinator was supported by a supplementary coordinator and resources in form of time and funds were provided for their work. A science education board of important actors was established as well and there was a well-developed organised network of teachers.

## 2. Science Education Development

The notion of '*Science education development*' is a superordinate term for activities that aim to improve science teaching and ultimately student learning outcome. In order to explore development of science education, it is necessary to consider factors that influence educational development in general.

Educational effectiveness research explores factors in schools and in the educational system that affect students' learning (Reynolds et al., 2014). In the 1980's, the focus in school improvement became practitioner-oriented (Hopkins, Stringfield, Harris, Stoll, & Mackay, 2014). Teachers were considered as pivotal because their actions in classrooms were found to explain a large proportion of the variance in students learning outcome (reviewed in Muijs et al., 2014). Therefore, teachers' learning communities were explored in order to achieve a deeper understanding of teachers' effect on students' learning in schools.

Schools particularly effective in facilitating learning have been described as '*Professional Learning Communities*' (PLCs) (Stoll & Louis, 2007). PLCs can be characterised by following dimensions: shared and supportive leadership, shared values and vision, collective learning and application, shared personal practice, supportive conditions in the form of relationships and structures respectively, and external factors (including parents, community, and central office) (Hipp, Huffman, Pankake, & Olivier, 2008, p. 175). This description of PLC includes actors who are not organisationally affiliated with the schools, and thus directed attention towards new factors despite the previous tendency to only consider teachers and school leaders as part of PLCs (Bolam et al., 2005).

The notion of PLCs has since then been broadened to include collaboration between schools. Hence, '*Networked Learning Communities*' (NLCs) has been used to describe '*groups of schools working together to enhance the quality of professional learning and to strengthen capacity for continuous improvement*' (Katz & Earl, 2010, p. 27). The notion is that students' learning depends on practices and structures of schools, which can be changed through interaction in and across schools in networks (ibid.). Networks between schools need facilitative structures in order to affect students' learning, and local districts are in positions to provide such structures (Hopkins, Harris, Stoll, & Mackay, 2010). This explains the increasing focus on collaboration and networks across schools and districts (reviewed in Hopkins et al., 2014). As emphasised in state of the art paper presented at the International Congress for School Effectiveness and Improvement in 2011, educational effectiveness research has thus evolved to focus more broadly to include districts and local authorities (Reynolds et al., 2014).

In the Danish context, school districts are governed by the municipal government (see Chapter 1 for description of Danish municipalities). Administrators at all district levels coordinate resources and directives affecting teachers' professional development (McLaughlin & Talbert, 2006). In this way, the administrative level plays an indirect yet important role. Schools are also influenced by other factors in the local community (e.g. demographic factors); the broader community (e.g. media); political decisions, and professional learning infrastructure (Bolam et al., 2005, p. 25). It is therefore a reasonable assumption that coordination of resources at the municipal level can have an influence on educational development. Such coordination is premised on the existence of relationships between actors from the district government as well as schools and other local influential actors. It is therefore necessary to focus on collaboration in order to improve education — not just in schools but district wide (Daly & Finnigan, 2010, p. 113). Few studies so far have explored the relationship between district level and student achievement (Hopkins et al., 2014) and whether leadership at the district level "*is an important part of the mix of actions that in the aggregate have a causal effect on student achievement. The answer is not obvious.*" (Marzano &

Waters, 2008, p.2). However, studies do seem to confirm that quality in district administrations impact student achievement (reviewed in Hopkins et al., 2014). This emphasises the multilevel complexity affecting school development and ultimately student learning. We do know that there is a correlation between schools considered to be PLCs and improved student learning outcome. This correlation is explained partly by teachers' connections to the world outside classrooms (reviewed in Bolam et al., 2005). This means, that PLCs depend on the process of *'interacting with and drawing on external agents'* (Bolam et al., 2005, p. 11). In the UK, Local Education Authorities has been shown to contribute to school improvement. LEA advisors serve as links to the external environment (Harris, 2001) and can thus play significant roles for students' learning. In this way, PLCs and schools in general can be considered to be complex open systems in dynamic interplay with influential actors both inside and outside the organisation. The diversity of such actors can provide access to a variety of resources, that teachers can draw upon in their professional development and teaching practices. *'Teachers' motivation and ability to learn, and to implement that learning in the classroom, depend on the support of the larger community'* (McLaughlin & Talbert, 2006, p. 89).

As part of the Danish school reform (as of august 2014)<sup>8</sup> schools are now required to engage external actors in the local community. Partnerships between schools and the local community are intended to contribute to a varied and differentiated teaching and thus to improved student learning (ibid.). Teachers are now expected to access and use local resources in their teaching on a regular basis (ibid). It is therefore highly relevant to include external actors in explorations into development of education, but because science is an integral part of society and the world around us, it may be particularly relevant for science education. *"Opportunities for learning science outside of school make a significant contribution to science education"* (Rennie, 2014, p. 120). Variation in teaching methods has been related to improved student performance (Reynolds et al., 2014) and considered as an effective way to deal with student diversity and *"help students learn more efficiently and effectively"*<sup>9</sup>. Many different actors can contribute to variation in teaching by providing access to relevant resources and facilitate their use in science teaching. In other words such actors can improve teaching by mobilising resources. Resources can include tangible resources, e.g. informal learning environments and materials, as well as intangible resources, e.g. knowledge, knowhow etc. (Tsai, 2000). These resources can influence science teaching directly (e.g. specific teaching materials), but some resources mobilised by actors influence science teaching indirectly by facilitating improvement of conditions for science teaching (e.g. political support, which can lead to reallocation of municipal funds). Therefore, I use the term 'development of science education' to refer to all activities that directly or indirectly facilitate mobilisation of resources for use in science teaching to ultimately improve teaching and student learning. In this way, support of science education is considered here to include other activities than only support of teachers' professional development.

This study seeks to explore municipalities as important arenas for science education development. The SM project sought to establish relationships between relevant actors to formalise the coordination of resources relevant for science education. Based on the argumentation here, the benefit of collected resources can be considered to facilitate improvement of science teaching and ultimately student learning. Therefore science municipalities were a relevant context for the current research project.

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<sup>8</sup> <https://www.uvm.dk/Uddannelser/Folkeskolen/Laering-og-laeringsmiljoe/Den-aabne-skole>, retrieved February 26<sup>th</sup> 2016.

<sup>9</sup> <http://oic.id.ucsb.edu/international-ta-handbook/teaching-undergraduates/teaching-student-diversity>, retrieved February 26<sup>th</sup> 2016.

### 3 Social Network Analysis

This chapter presents an introduction to social network analysis (SNA) and how SNA has been used in educational development research. I highlight important considerations regarding inferences based on SNA data and describe how my study addresses social networks that have not yet been described in the context of educational development.

#### 3.1 Social Network Analysis

SNA was initially developed within the field of sociometry, which took its starting point around the first world war and was described by Jacob L. Moreno a few decades later (Moreno, 1941). Sociometry can be defined as *'the measurement of interpersonal relations in small groups'* (Wasserman & Faust, 1994, p. 11). Sociometry present a systematic approach to study interpersonal relations (de Nooy, Mrvar, & Batagelj, 2005). A social network can be defined as a set of nodes (often individuals) connected by one or more links (relationships) (Marin & Wellman, 2011). The nodes in social networks are not by definition individuals, but can also be groups of populations, e.g. organisations or corporate subunits. SNA generally considers one of two types of networks: whole networks or ego-centered networks (Bernard & Gravlee, 2014). Whole networks exist within a bounded space which is delimited either geographically or socially (e.g. membership of a given organisation) (Bernard & Gravlee, 2014). Egocentric networks considers the *'nodes that share the chosen relation(s) with the ego and on relations between those nodes'* (Marin & Wellman, 2011, p. 20).

The concept of networks is not a new metaphor (Jones, 2004b), but has been widely used. The network metaphor has been used to describe a variety of issues (selected studies reviewed in Wasserman & Faust, 1994, p. 5-6). *"Networks are providing an interdisciplinary framework for understanding a wide range of phenomena."* (Jones, 2004a, p. 82). This being said, the concept can not be used uncritically as a mean to solve all kinds of practical issues (Jones, 2004a). As emphasised by Ingraham, usefulness of the network metaphor depends on an understanding of the inherent complexity and thus requires that networks are not treated as two-dimensional entities (Ingraham, 2004). Otherwise, the illuminated issue risks to be subjected to oversimplification (ibid). In the current study, the network metaphor is used to illuminate relationships between the diverse actors who are involved in development of science education in selected Science Municipalities (so-called municipal science education networks (MSE networks))<sup>10</sup>. The actors are thus connected in social networks based on their different engagement in this development. The mapping of relationships in these social networks is based on their discussions about science education development (further discussed in Chapter 4 and Paper 2). In this way, science education development can be considered as the ultimate purpose of these networks, even though the actors contribute in different ways. To any given time, a MSE network is comprised by a discrete set of actors and the relationships between them. Such network structure change over time, since the actors and their relationships are dynamic (see Paper 2 and further discussion in Chapter 8). In this context, *'Structure'* is to be considered as *'regular patters in relationships'* (Wasserman & Faust, 1994, p. 3). (However, there exist other non-compatible definitions of *'network structure'* (Brown & Keast, 2003).

Jones highlights a crucial consideration regarding network studies: *"A fundamental question about the use of the network metaphor is whether we are dealing with networks as a kind of reified structure or topology or with networks as a process, a dynamic series of relationships... There is*

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<sup>10</sup> Similarly, MSE network can exist in municipalities that were not involved in the SM project, but which have a focus on development of science education. In this study, MSE networks are explored in selected Science Municipalities.

*nonetheless a fundamental difference between viewing networks as processes and reifying the process such that representations of process in topologies are taken to be the network itself.”* (Jones, 2004b, p. 195-196). Based on this distinction, I find it important to emphasize that what is achieved, when mapping social networks in SNA studies, is a representation that (at best) approximates structures of the ‘real-life’ social network in questions. Through network mapping tasks, it is thus only possible to achieve a snap shot of structures in the social networks. This means that a sociogram represents the structures in a social network at a given point in time. This distinction between social network and network representation should be reflected in the terminology used in SNA studies. The research fields, where SNA is being used, often determine the terminology. Therefore the nodes in SNA studies have different terms, e.g. ‘actors’, ‘agents’, ‘points’, ‘vertices’, etc. The relationships connecting the nodes are likewise being denoted by different terms, e.g. ‘links’, ‘ties’, ‘relationships’, ‘lines’, ‘edges’, etc. Ingraham argues that there is a risk of presenting an “*inaccurate abstract network metaphor*”, when actors (in Ingraham’s study: learners) are considered as nodes (Ingraham, 2004, p. 192). In order to overcome any possible confusion in the thesis according to references to MSE networks (as social networks existing in the municipalities) and to representations of the MSE networks (presented in sociograms), respectively, different terms are explicitly used. When considering the MSE networks, the members are denoted as actors<sup>11</sup> and the connections between them are denoted as relationships. When referring to the mapped networks, the members are denoted as vertices<sup>12</sup> and the connections between vertices are denoted as links. This aims to clarify the distinction between the ‘real-life’ social networks and the representations in sociograms, which present an approximated illustration of the ‘real-life’ network.

Social network researchers tend to differentiate between ‘*network theory*’ and ‘*theory of networks*’ (Borgatti & Ofem, 2010, p. 22; Borgatti & Lopez-Kidwell, 2011, p. 40). Network theory considers the consequences of network structures, whereas theory of networks addresses the formation of relationships. In terms of this distinction, this project considers network theory because a snapshot of the existing MSE networks is explored to elucidate the consequences of the relational structures for development of science education development.

Both the actors and the types of relationships that connect them define social networks. Borgatti and Ofem present one way to describe the different types of relationships connecting actors in social networks. In their presentation these types include: similarities (e.g. location, membership, attitude); social relations (e.g. kinship); mental relations (e.g. affective and cognitive relations); interactions (e.g. ‘talked to’, ‘helped’ etc.); and flows (e.g. information) (Borgatti & Ofem, 2010, p. 19). The relationships between actors can be symmetric or asymmetric (and not necessarily reciprocated) (Hanneman & Riddle, 2011a, p. 332). This results in undirected and directed networks, respectively.

In a given social network, the actors can be connected by several types of relationships. The type of relationship that connected actors in the MSE networks belonged to the category of interactions, since the relationships were based on discussions. The discussions could potentially lead to flow of resources, e.g. in the form of information, knowledge, ideas etc. One way to distinguish different kinds of flow in social networks is to consider the purpose of exchanging resources. When relationships are used to exchange resources that can facilitate achievement of an organisational goal (in the given social network), the relationships can be considered as ‘*instrumental*’; whereas relationships, that are used to exchange resources that are not directly aimed at achieving organisational goals, can be considered as ‘*expressive*’ (Moolenaar & Slegers, 2010, p. 100). In

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<sup>11</sup> In some cases, the actors are called network members if it is needed to set this out explicitly in order to avoid possible confusion.

<sup>12</sup> When referring directly to presented sociociograms though, the vertices are referred to as ‘nodes’.

social networks and among given actors, both types of relationships can exist, but in the context of mapping the MSE networks, the focus was exclusively on instrumental relationships (since the relationships considered development of science education in the municipality), even though there is no plain distinction between expressive and instrumental relationships in real-life social networks.

Social networks can be explored on the network level and on the individual level. These approaches provide different forms of knowledge about the social networks. SNA on the network level focuses on the overall relational structures in a given social network. Different measures can be used to characterise social networks, e.g. size (number of actors); number of relationships; density (the number of actual relationships divided by the number of hypothetically possible relations (Wasserman & Faust, 1994, p. 129)); number and structure of communities (*'sets of nodes with a high density of internal links, whereas links between compartments [communities] have a comparatively lower density'* (Lancichinetti & Fortunato, 2009)); core-periphery structure (a network, which cannot be divided in exclusive subgroup, though some vertices are much better connected than others (Borgatti & Everett, 2000, p. 376)); centralisation (the degree to which a set of actors are organized around a central point (Haythornthwaite, 1996, p. 333)).

The relational structures result in different central positions in social networks. This gives rise to different centrality measures. Centrality is a way to consider 'importance' of members in social networks (van der Hulst, 2011, p. 260). Some centrality measures are adjacency-based (e.g. degree, betweenness and closeness centrality), whereas others are probabilistic (e.g. Google PageRank centrality) (Bruun & Brewe, 2013). Centrality measures are attached with different potentials, e.g. for communication activity, communication control, and communication efficiency (Freeman, 1979). The centrality measures indegree, closeness, and betweenness are defined and explored in Paper 3.

Based on analyses on network level and individual level, SNA holds many possibilities to explore structures in social networks. SNA has thus been used in many different research fields ranging from research in e.g. organisational development (e.g. McGrath & Krackhardt, 2003; Waldstrøm, 2003; Tsai, 2002), trading (e.g. Kim & Shin, 2002), social networks of individuals with infectious diseases (e.g. Stephenson & Zelen, 1989), etc. In the past decade, SNA has been applied in educational research as well and application in this field will be addressed in the following.

### 3.2 Social Network Analysis in educational research

Social networks exist at many levels of the educational system. *"The concept of 'network' has entered teacher, educational manager and policy maker thinking, although this is poorly defined"* (Carmichael et al., 2006, p. 231). Educational networks has been described as *'potential outcome of collaboration and professional development'* (Carmichael et al., 2006, p. 217). However, it was shown in a study of social networks of teachers, school coordinators and local authority staff that conceptualization of networks were eclectic and confusing and that in some cases *"the concept of 'the network' had a metaphorical value (but which would evoke different images for different people)"* (Carmichael et al., 2006, p. 218). The varied use of the concept, may explain a widely distributed inconsistent use and understanding of the network term.

Educational researchers have been engaged in SNA studies at different levels to seek knowledge about mechanisms in educational development. The aim for educational development is improved teaching and student learning. Students thus represent the primary target for teaching and student networks have been a field of interest (e.g. Bruun, 2012). Since teachers are responsible for teaching practices, teacher networks have also been explored (e.g. Baker-Doyle, 2015). School leaders are important for school development and affect conditions for teaching (McLaughlin &

Talbert, 2006, p. 98). Therefore school leaders' relationships have been explored, e.g. in social networks of school leaders and teachers (e.g. Pitts & Spillane, 2009). Social networks of school administrators in school districts address the strategic level of educational development. Hence, social networks between school administrators at different levels in districts have been investigated as well (Daly & Finnigan, 2010, 2011).

In the following, I describe selected SNA studies focused on these different levels of the educational system and on social networks with different aim (support networks, advice networks, knowledge networks etc.). Other studies present different aspects of educational networks, but these studies are selected to illustrate the wide spectrum of potentials residing in this methodological approach and also to highlight cautions regarding SNA studies.

To begin with the primary target for educational development, SNA offers a means to identify and explore student networks. One way to approach student networks was illustrated by Bruun, who used data from students' self reports to map social networks (Bruun, 2012, p. 64). This longitudinal study revealed student interactions during teaching and learning activities. It served as a basis to achieve understanding of dynamics in student networks. By exploring development of student networks over time, it was possible to consider whether any changes in relational structures could be connected to certain teaching interventions. Another study by Bruun explored the correlation between network structure and student attributes (Bruun, 2012). It showed to be possible to investigate the community structure in student networks. Bruun found that students segregated according to certain attributes, e.g. class and to a lesser extent gender (Bruun, 2012, p. 70; Bruun & Bearden, 2014).

Results from studies of student networks can be used to achieve an understanding of the correlation between learning activities in teaching and student network dynamics. This can serve as knowledge to guide teachers in making informed decisions about their teaching, e.g. when considering how to divide students into teams during activities, depending on intentions of mixing students or maintaining groups, respectively.

Moving from the students to the teachers, SNA studies of teacher networks can be used to investigate the different kinds of social networks that teachers engage in as part of their professional practice. It became clear from the current study, that in some Danish municipalities, 'teacher networks' (in Danish, lærernetværk) is a term used commonly to describe groups of teachers working together on different premises. These groups of teachers were characterised differently according to included members, overall objective, types of relationships, and quality in relationships. Despite of differences, they were often described by the common term 'teacher network'. Since such groups of teachers are not the focus in the current research project, the overall term 'organised network of teachers' will be used when referring to them, in order to distinguish this use of the network term from the use in municipal science education networks (which encompass other actors than teachers). When investigating networks of teachers, Baker-Doyle focused on support networks for first-year teachers and showed that teachers tended to receive support from colleagues who worked in their own school and to whom they had strong personal relationships (Baker-Doyle, 2015). Information about who teachers turn to for professional support is important to achieve an understanding of how teachers' practices are influenced and by whom. This is crucial knowledge for actors who wish to support teachers' professional development to achieve improved teaching. In this study, it is worth to notice that development of teaching is not always dependent solely on professional relationships, but personal relationships also affect the structures of support networks. Some factors, that affect educational development, seem to be placed outside the immediate influence of e.g. school leaders or other actors who intend to support

teachers' professional development for improved teaching. I find this especially interesting, because it emphasises the complexity in development of teaching and therefore serves as an incentive to think more broadly about ways in which to support teachers.

Educational development is affected not only by teachers' practice, but also by conditions for teaching, which is influenced by school leadership (McLaughlin & Talbert, 2006, p. 98). Therefore school leadership has gained a lot of attention in educational research. Friedkin and Slater investigated school leaders' centrality and school performance (Friedkin & Slater, 1994). They selected indegree as centrality measure for school leaders in teachers' advice network and found an association between school leaders' indegree centrality and school performance. In addition to aspects of formal school leadership, SNA can also be used to identify informal leadership. Pitts and Spillane used SNA in schools to study informal leadership interactions, which were not captured by the formal organisation in schools (Pitts & Spillane, 2009).

Broadening the perspective, schools are placed in districts (or municipalities in the Danish context) managed by local authorities. Daly and Finnigan used a mixed methods SNA approach to examine communication and knowledge networks among central office administrators and school leaders in a district under educational reform. In a case study, they found the relationships between the administrators and school leaders to be sparse (Daly & Finnigan, 2010). They also investigated the connections between school administrators and district administrators in another district under the same reform (Daly & Finnigan, 2011). The educational reform had special focus on increasing relationships between these two groups of administrators, but Daly and Finnigan found that most of these relationships remained unchanged. In this case, the SNA study could be used to assess the achievement of the reform objective. Hite, Williams, and Baugh (2005) have also explored social networks of public school administrators (Hite, Williams, & Baugh, 2005). They explored networks of district superintendents, assistant superintendents, district directors, school principals, and assistant principals. They found that administrators used multiple networks, e.g. resource network and support network, to achieve their organisational objective.

As these studies illustrated, SNA can be used to reveal structures among groups of actors affiliated with different organisations and levels in the educational system. It is important to emphasise that mapping of such social networks provides a simplified overview of the dynamic relationships among the actors involved in the educational networks. The appealing illustrative representations of social networks (sociograms hereafter) may induce one to jump to conclusions about connections between relational structures and educational development. As described in the studies, SNA can be used to identify important actors and relationships among them. It is important to explore correlations between these relational structures and different aspects of development carefully to avoid making misleading inferences. Taking the study of school leaders' centrality as example, it is necessary to consider the aspects of school leaders' positions that might contribute to a correlation between their centrality and school performance. It is important not to consider school performance as a direct result of their centrality, even though a correlation was found. Similarly, it is crucial to consider which performance measures might be appropriate for assessing educational development if the information is to be used to guide school leaders' decisions. Overall, it is important to emphasise explicitly what SNA data can tell us, and just as important what SNA cannot tell us about structures in social networks and educational development.

As the examples above illustrate, it is valuable to supplement quantitative SNA methods with qualitative studies. Qualitative data can reveal aspects that are not elucidated by a quantitative SNA

approach. Therefore mixed methods approaches are also common practice in SNA studies of educational networks.

As emphasised by others, relationships, not just between actors in schools but throughout entire districts, seem to be important for educational development (Daly & Finnigan, 2010; Sillasen & Valero, 2013). Despite of this acknowledgement, the studies described here address social networks of typically only one type of actor (e.g. teachers) or few types of actors (e.g. different administrators on school and district level). None of the studies explored social networks comprised of all actors involved in educational development regardless of their hierarchical or organisational affiliation in the district. What is common for these studies is that the social networks in question are pre-determined (i.e. approached through saturation sampling (Lin, 1999)), because they focus on certain types of actors. Taking the study by Hite, Williams, and Baugh as example, it was possible to point out all 38 public school administrators in the district before exploring the relationships between them. This example illustrates a general tendency to look isolated at educational networks where the actors are already defined by organisational affiliation. What I have done is to explore social networks comprising all the different actors who are involved in development of science education regardless of their affiliation to specific organisations or hierarchical levels in the municipalities. These actors are not part of a predefined social network, but they are connected as a result of their engagement in science education development. Some of them may seem to be obvious members in the MSE network (e.g. MSE coordinators and local science education supervisors (naturfagsvejledere in Danish)), whereas many other actors can turn out to be involved in these networks even though science education is not their primary field (e.g. actors from the administrative level). At the same time, there might be some actors, who are supposed to play significant roles in development of science education, but who have other priorities, which impede their engagement in the work, and who would therefore not actually be members of the MSE networks. Therefore respondent-driven sampling is needed to approach the actors empirically (described in Paper 2 and Chapter 4). For these reasons, such social networks are naturally harder to capture, which may be one reason why they are not well described in the literature. The SM project evaluation indicated that such compound social networks seemed to hold great potentials for development of science education in the Science Municipalities, because it enabled overview of existing resources (e.g. activities) and hence utilization thereof. In addition new resources emerged as result of the relationships among the actors (Sølberg & Jensen, 2011). Therefore, I set out to explore these elusive but important social networks.

In order to use SNA studies in educational development research, it is crucial that the relational structures are presented with high accuracy and thus reflect the existing social networks. Different approaches can be used to test validity in SNA studies. One approach is use of cognitive interviews where respondents are asked to 'think aloud' as they answer the SNA questionnaire. Pitts and Spillane used this approach to test a School Staff Social Network Questionnaire. During the interviews they asked the respondents how they decided which names to fill in. The respondents were also asked to explain if they disregarded any names in their answers and in these cases why. In addition they were asked if they interacted or talked with any other people about their teaching and in these cases why they chose not to include them (Pitts & Spillane, 2009, p. 207). In this way they tested whether the respondents' interpretation of the survey questions aligned with the interpretation intended by the researchers when designing the questionnaire. This kind of validation study provides information about how questionnaires can be revised to ensure an alignment between the respondents' interpretation of questions and researchers' intention. This is a way to test the SNA instrument to ensure valid network data.

When network data is collected, the relational structures can be represented in sociograms. A sociogram is ‘a graphical representation of group structure’ (de Nooy et al., 2005, p. 4) Such sociograms can be presented to the respondents for validation purposes. By informing the respondents about their own position in the sociogram, the respondents can be used to assess the ‘correctness’ of the sociogram. This is a common way to test the validity (McDonald, 2003). However, results from such validation studies do not seem to be presented very often in educational SNA studies. I consider it important to present the process of validity tests in these studies because this serves to maintain the necessary awareness regarding the validity of resulting network data. If the alignment between the network representations in sociograms and real-life social networks is not questioned and explored, this could result in misleading inferences based on SNA studies. Therefore, I present a validation study where the respondents were consulted, not only in the process of generating and validating the SNA questionnaire, but also in assessing the correctness of the resulting sociograms (see Chapter 4 and Paper 2). This provided crucial information about the validity of the network data. If respondents are informed about their position and asked to validate the sociogram, there could be confirmation biases, which could be problematic for the interpretation of the results. When informed about their position, the respondents may base their reflections about the sociogram on this information, and this could influence their ability to validate the correctness. Therefore I used another approach and explored the validity by letting the respondents point out the position that they suggested were their own in the sociogram. This provided an alternative approach to explore how exhaustively the network data described the MSE networks. Being aware of the premises (further discussed in Chapter 6), such approaches could be used in other SNA studies.

## 4 Methodology

This chapter addresses the methodology and my considerations about the research design in the quantitative and qualitative part of the study. It thus serves as a supplement to Paper 2, which presents the validation study.

### 4.1 A mixed methods study

In the current study, SNA provided a means to uncover and map the actors and the relationships connecting them in MSE networks. This approach enabled identification of central actors who were subsequently selected for the qualitative part of the study based on the resulting data about their network position. The study was thus planned as a fixed mixed methods study (Creswell & Clark, 2011). ‘*Fixed mixed methods*’ means that the methods and the order in which they were applied were planned before the data collection (Creswell & Clark, 2011, p. 54). Therefore, the study comprised the quantitative SNA study used to identify network members and map the relational structures in MSE network followed by the qualitative study based on interviews with central actors as described. A mixed methods approach was selected because each method alone would be inadequate to answer the overall research question: ***How are central actors in social networks in Danish Science Municipalities affecting development of science education?***

The qualitative study was needed in order to complement results from the quantitative study (Greene, Caracelli, & Graham, 1989). The SNA study preceded the qualitative study and the timing of the methods was thus sequential. Hence, the study can be described as an *explanatory sequential design study* (Creswell & Clark, 2011).

A procedural diagram of the phases in the study is presented in Figure 1 to give an overview of the research design.

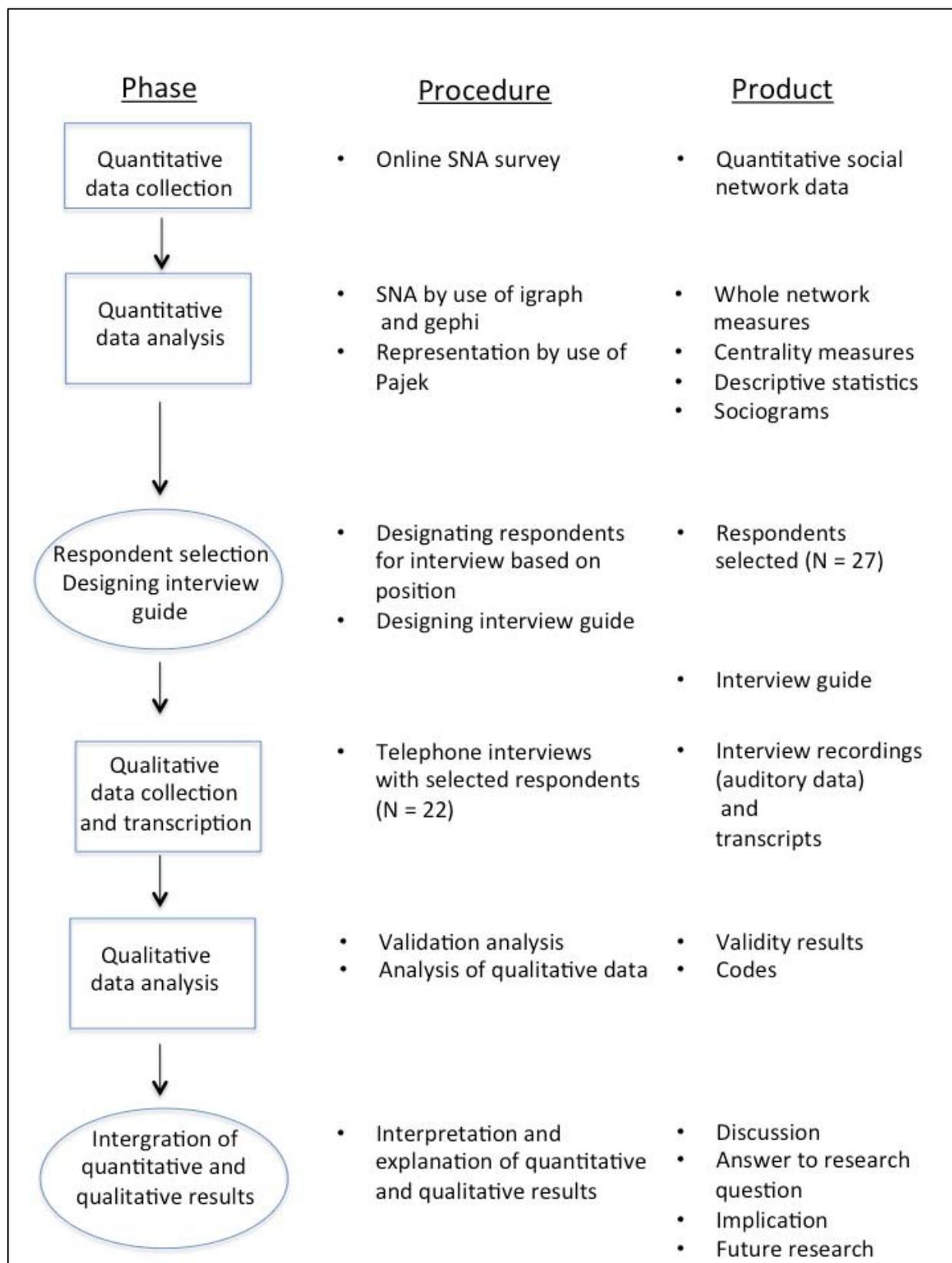
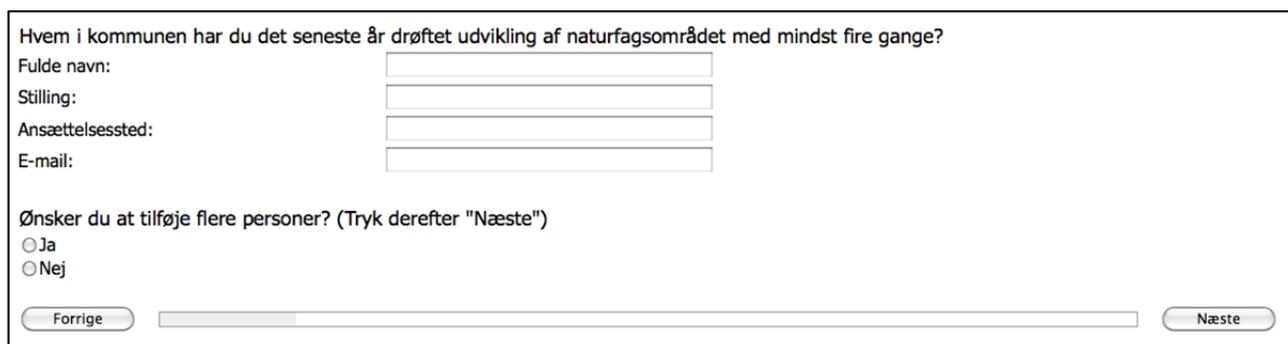


Figure 1: A procedural diagram of the study. The phases (left column), the procedures (middle column), and the product (right column) for each phase are presented. The figure is developed based on the framework used in the procedural diagram from (Ivankova & Stick, 2007, p. 98).

## 4.2 SNA data collection

### 4.2.1 SNA questionnaire design

The instrument used to collect quantitative network data was an online SNA questionnaire. In the questionnaire the respondents were asked to answer following name generator question (Marsden, 2011): ‘Who within the municipality have you discussed development of science education with at least four times in the past year?’ It was used to identify the respondents’ alters, i.e. the actors to whom the respondents had a direct relationship (Hanneman & Riddle, 2011b, p. 340). As shown in Figure 2, the respondents were also asked for background information about their alters’ name, formal position, place of employment, and email.



Hvem i kommunen har du det seneste år drøftet udvikling af naturfagsområdet med mindst fire gange?

Fulde navn:

Stilling:

Ansættelsessted:

E-mail:

Ønsker du at tilføje flere personer? (Tryk derefter "Næste")

Ja

Nej

Figure 2: An illustration depicting the name generator question in the SNA questionnaire. The question reads: ‘Who within the municipality have you discussed development of science education with at least four times in the past year?’ The text in the left column reads: Full name, Formal position, Place of employment, email. The text in the bottom reads: ‘Do you wish to add more people (Then click “Next”’). The options are ‘Yes’ and ‘No’, respectively.

The name generator question was supplemented by name interpreter questions. Name interpreter questions characterise the alters or the relationships with alters (Marsden, 2011). These questions were included to get an insight into the qualities of the relationships. As is seen from Figure 3, the name generator questions included:

*‘I have a connection to other people, who contribute to science education, through him or her’*

*‘He or she inspires me in my work to improve the quality of science education’*

*‘I turn to him or her for advice, when I have a new idea for improving science education’*

*‘He or she has had a positive influence on my work to improve science education in this past year’*

*‘He or she has had a negative influence on my work to improve science education in this past year’*

*‘Among the people named, he or she is especially important for the overall improvement of science education in the municipality’*

Marker for hver af personerne, hvilken af følgende beskrivelser, som passer til din relation til vedkommende (du kan vælge flere):

	Gennem ham/hende har jeg har kontakt til andre personer, som bidrager til naturfagene	Han/hun inspirerer mig i mit arbejde med udvikling af naturfagsområdet	Jeg går til ham/hende for at få sparring, når jeg har en ny ide til udvikling af naturfagsområdet	Han/hun har haft positiv indflydelse på mit arbejde med udvikling af naturfagsområdet det seneste år	Han/hun har haft negativ indflydelse på mit arbejde med udvikling af naturfagsområdet det seneste år	Af de nævnte personer, er han/hun særlig vigtig for den samlede udvikling af naturfagsområdet i kommunen	Andet
Person A	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Person B	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Person C	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Eventuelle kommentarer til spørgeskemaet eller din besvarelse:

**Figure 3: An illustration depicting the matrix of name interpreter questions in the SNA questionnaire. The title reads: ‘Indicate for each of the persons, which of following descriptions that applies to the relationship you have to the person in question (you may choose several)’. In the left margin, the alters named by the respondent are listed in rows. From left to right, the text on top of each column reads: ‘I have a connection to other people, who contribute to science education, through him or her’, ‘He or she inspires me in my work to improve the quality of science education’, ‘I turn to him or her for advice, when I have a new idea for improving science education’, ‘He or she has had a positive influence on my work to improve science education in the past year’, ‘He or she has had a negative influence on my work to improve science education in the past year’, ‘Among the people named, he or she is especially important for the overall improvement of science education in the municipality’, and ‘Other’. In the bottom of the questionnaire, the text on top of the box for open-ended responses reads: ‘Possible notes to the questionnaire or your response’.**

The first three of these questions indicated what role the alters had in relation to the respondent, i.e. as matchmaker, inspirator, and advisor. The last three questions were included as an attempt to identify actors who served as facilitators or hindrances for others in the MSE network. By presenting the name interpreter questions in a matrix (see Figure 3), respondents were able to choose whether they wanted to answer them ‘by alter’ or ‘by question’ (Lima, 2010, p. 253). This was done to facilitate the respondents when they filled in the answers, because I assumed that the responses were most reliable when the respondents were able to answer in the order that suited them best. During the analysis of the qualitative data, it turned out that the name generator question provided sufficient data to answer the research question without including the name interpreter questions. Therefore, data resulting from the name interpreter questions is not dealt with further in this thesis.

The SNA questionnaire was tested by a group of test respondents before it was used in the pilot study in Mun U (von der Fehr & Sølberg, 2013). The test respondents were selected to represent different organisational categories, because the possible target groups in the survey were actors from different subunits in the municipalities (e.g. educational institutions, informal learning environments, and the administrative and political level). The group was composed of nine test respondents: five MSE coordinators (from different science municipalities and with different employment conditions); one head of a municipal school department; one high school science teacher; one vice school administrator, and one high school administrator. The test respondents were interviewed either by telephone or face to face. Following a semi-structured interview guide the test respondents were asked to reflect on the following aspects of the SNA questionnaire:

- Usability of the online questionnaire
- The wording of the introduction text in the preface of the questionnaire
- The wording of the name generator question
- The wording of the name interpreter questions and the degree to which they were exhaustive

The test respondents were asked to consider whether the wording in the questionnaire addressed the different potential respondents. In addition, they were asked to estimate the number of actors they would name if they were to answer the name generator question genuinely. Before ending the interviews, they had the opportunity to address any aspects that were not dealt with in the interview questions. Based on data from the interviews with the test respondents, the wording of the name generator question was adjusted. The verb was changed from ‘co-operate’ to ‘discuss’ because test respondents’ interpretations of ‘co-operate’ were ambiguous. The frequency criterion was changed from ‘once a month’ to ‘four times in the past year’, because it became clear in the interviews that the first frequency criterion would lead to exclusion of important actors in mapping of the social networks. After these adjustments, the questionnaire was used in the pilot study in Mun U before data collection was initiated in the following three municipalities.

#### 4.2.2 Respondent-driven sampling

A respondents-driven sampling method, called snowball sampling, was used (Gile & Handcock, 2010; Illenberger & Flötteröd, 2012). ‘*Snowball sampling, where a sample of seed respondents nominate later respondents, is often used as a way to define whole network boundaries when the network to be studied is known (such as a gang) but where network members are not limited to a known geography and there are no list of network members*’ (Bernard & Gravlee, 2014, p. 636). In this study, the MSE networks were known to exist in the selected Science Municipalities (based on data from the evaluation of the SM project), but no list of network members existed.

The questionnaire was initially sent to the MSE coordinators (seed vertices constituting iteration 0). Afterwards, the questionnaire was sent to the alters named in their responses, which gave rise to the following iterations. The boundaries of the sociograms were thus set by the relationships, the respondents had to other actors in the municipality.

Data from iteration 0 presented the MSE coordinators’ ego-network. Some research fields, e.g. social media networks, consider different degrees of ego-centric networks. The so-called “*1-degree*” ego network include a given actor and the alters connected to this actor (Hansen, Shneiderman, & Smith, 2010, p. 36). The “*1.5-degree*” ego network also includes relationships between these alters (ibid.). The “*2-degree*” ego network includes all alters’ alters and not only the alters shared with the ego (as in the 1.5 degree ego network) (ibid.). In the current study, the snowball sampling can thus be considered to be initiated as an ego centric network analysis, but since the sampling is continued to approximated exhaustion<sup>13</sup> (see Paper 2), the sampling provides an overview of more than the MSE coordinators ego network, but is instead used to define the boundaries of the whole MSE network as argued by Bernard and Gravlee (Bernard & Gravlee, 2014, p. 636).

Another approach to identify actors in a social network is termed *expanding selection* (Doreian & Woodard, 1992, p. 219-220). In this approach, the sampling begins with actors who are defined to be part of the social network, but only alters connected to more than one of the network members are included. However, in this study, it was important also to identify actors who were connected to the rest of the social network through relationship to only one other actor. This way, it was possible to explore whether parts of the social network were weakly connected to the rest of the network. The snowball sampling approach (in contrast to the expanding selection) thus reduced the risk of missing parts of the social network during the mapping.

The SNA data collection followed a fixed procedure to ensure that all respondents in the four municipalities were given the same period of time to answer the SNA questionnaire. The data

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<sup>13</sup> The sampling was terminated, when no new alters emerged in the responses from the last iteration, or alternatively when only one or two new alters emerged, who had affiliation with an organisation already included in the mapping.

collection spread over several months, because of the iterative procedure. The MSE networks in Mun U and Mun L were exhausted after iteration 3; in Mun I after iteration 4; and in Mun S after iteration 5. Figure 4 shows a time line for the SNA data collection, the following quantitative data analysis, and the interviews in the qualitative study.

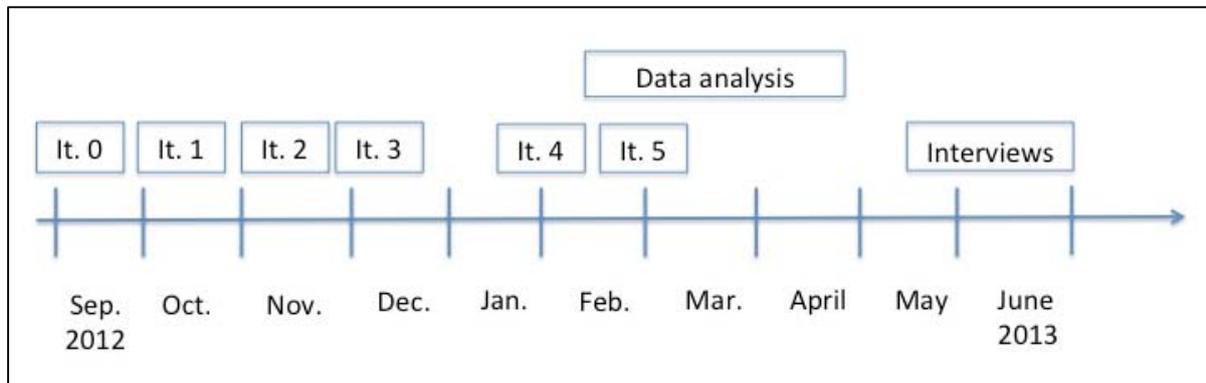


Figure 4: Illustration of the time line during SNA data collection, quantitative data analysis, and interviews in the following qualitative study. It. = iteration.

The following time schedule was applied:

- SNA questionnaire distributed day 1 (indicating a 10 day response deadline)
- Reminder sent day 11 (indicating an extended 7 day response deadline)
- Reminder sent day 18 (indicating an extended 5 day response deadline)
- Reminder sent day 22 (indicating an extended 3 day response deadline)

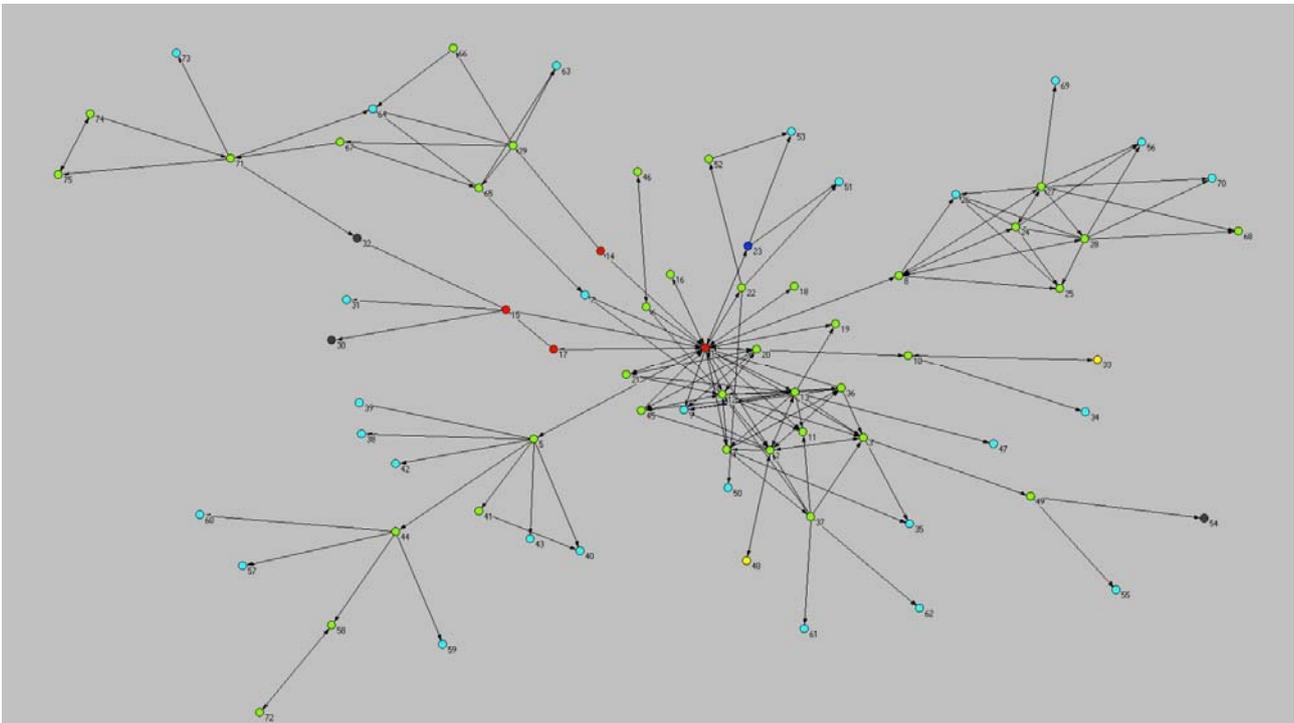
This time schedule was applied in each iteration in the municipalities (except in the pilot study, where the schedule varied slightly from this). As can be seen from Figure 4, data collection was planned to pause around the holidays. This was done to ensure that the respondents were given the same period of time to reply in spite of the school break.

Following the time schedule for questionnaire distribution and reminders, each iteration spanned a period of almost one month. Therefore the period for data collection was quite long and this could be a reason for cutting down the number of survey reminders sent to the potential respondents, who had not responded to the inquiry. But it turned out to be relevant to include as many as three reminders in the data collection procedure because some respondents did actually respond after receiving the third and last reminder. Whether this was caused by the number of reminders or because of the different wording in the introduction mail in the third reminder was not clear. However, it indicated the importance of including survey reminders to increase the response rate. After distributing the SNA questionnaire, I kept track of the responses. Some respondents started answering the questionnaire but stopped before completing. In those cases, I sent them an email offering help in case of any questions about the questionnaire or any technical problems. These email correspondences were formulated in a neutral tone in order not affect the respondents' response to the questionnaire. Though this was a time consuming process, this follow-up correspondence with respondents was important in optimising the number and the quality of responses.

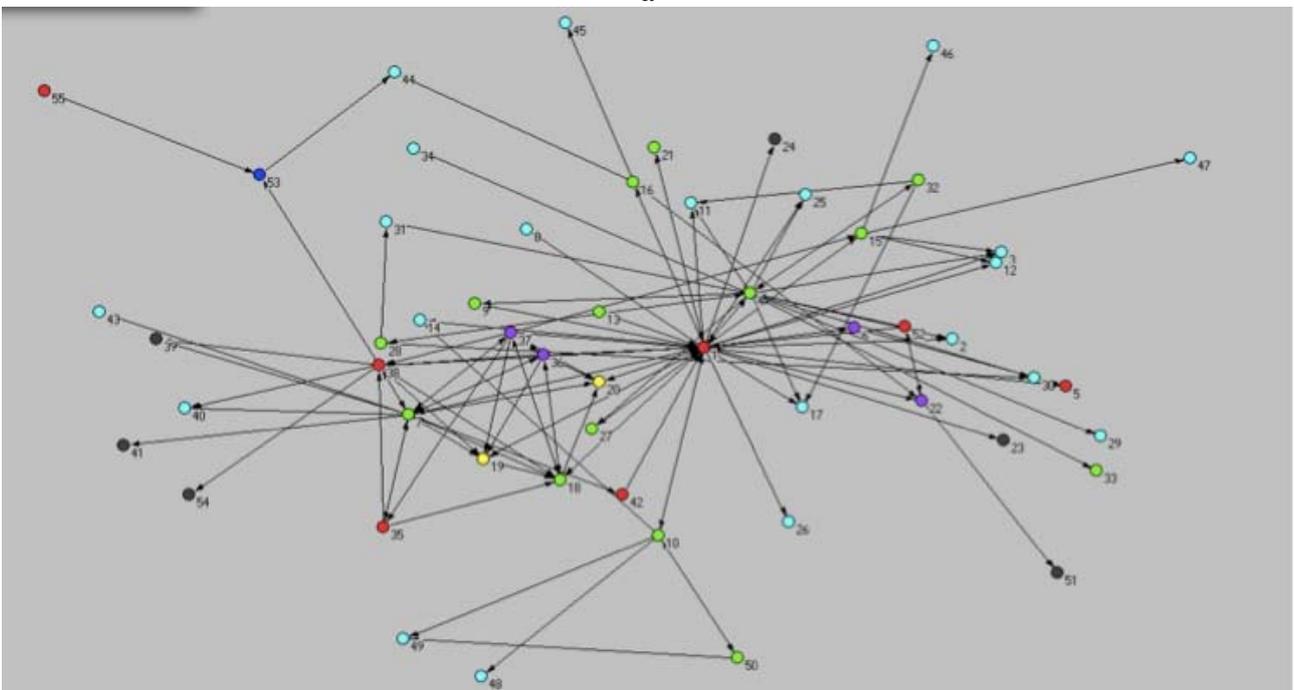
### 4.3 SNA data analysis

Certain criteria were included in the name generator question: a frequency criterion for the discussions between respondent and alter, and a criterion for municipal affiliation for the alters named in the responses (further discussed in section 4.6.1). In cases where I suspected that one or

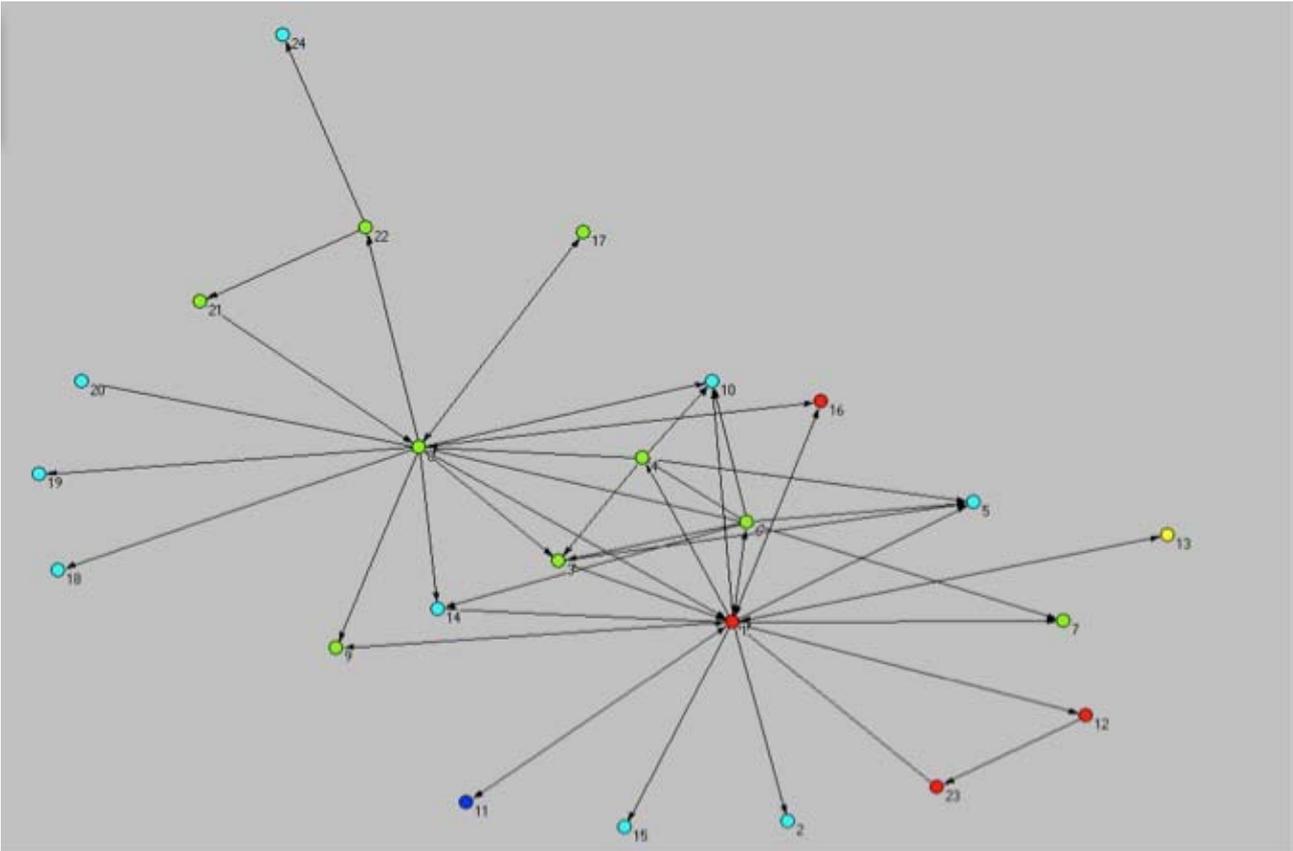
more of these criteria were not met, I contacted the respondents for clarification. These cases included examples of more sporadic discussions and discussions with actors who could not be considered as affiliated with the municipality. Alters who did not meet these criteria were removed from the data set and data was thus cleaned up to eliminate invalid information before data analysis. Sociograms of each MSE network were created by use of Pajek (de Nooy et al., 2005). Sociograms representing each MSE network are shown in Figure 5.



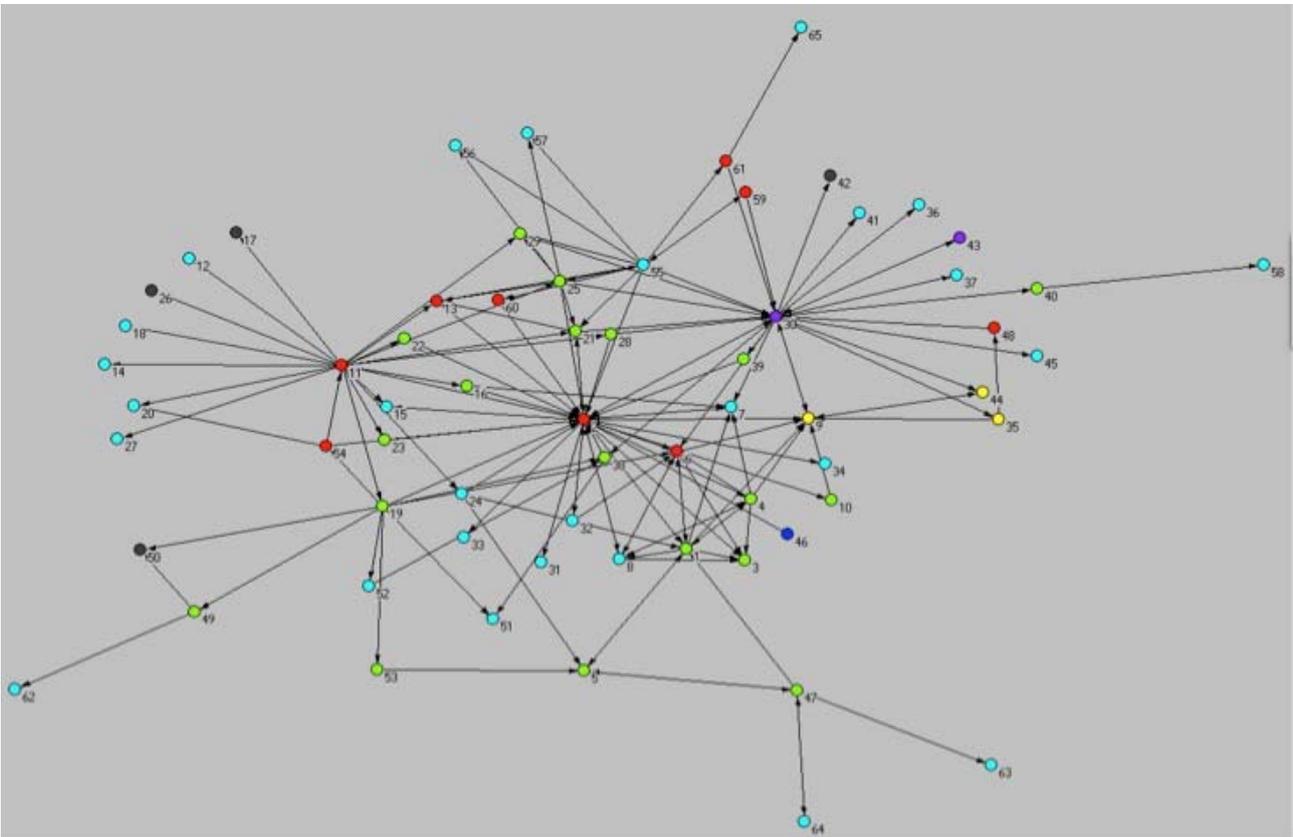
a



b



c



d

Figure 5: Sociograms based on network data from sampling of the MSE networks in each of four municipalities: a: Mun S; b: Mun I; c: Mun L; d: Mun U. Each node has a number and represents an actor and each arrow (link) represents a relationship between two actors. The arrowroot originates from the actor who has named an alter, and the arrowhead points to the alter, who has been named. The following colours of the nodes depict the organisational categories that each actor (who provided a positive response) was affiliated with; Red: administrative and political level; green: educational institution; yellow: informal learning environment; dark blue: enterprise; purple: other. In addition, dark grey nodes depict actors that provided a negative response, whereas turquoise nodes depict actors, who provided no answer.

In the sociograms, each node represents an actor and each arrow (link) represents a relationship between the two actors. The colours of nodes depict the organisational affiliation for the actors, who provided a positive response (see further explanation in Figure 5 text). The sociograms also represent the respondents, who provided a negative answer (i.e. respondents who claimed not to have discussed development of science education with anybody), and the network members, who did not provide an answer. The sociograms in Figure 5 was used in the interviews with central actors in the qualitative study.

The data was analysed by use of igraph and gephi software<sup>14</sup>. Network level measures were calculated to give an overview of the four MSE networks. Selected network measures are presented in Table 2 to illustrate what kind of information network analysis can provide.

	Mun S	Mun I	Mun L	Mun U
Network size (no. of vertices)	75	55	24	65
No. links (relationships)	175	128	54	157
Density <sup>15</sup>	0.0315	0.0431	0.0978	0.0377
Number of communities*	8	2	1	2

Table 2: Presentation of selected network measures based on network data from the four MSE networks. \*The number of communities was calculated by use of Infomap community detection algorithm.

Measures like the selected ones presented here can provide a general insight about structures in social network. As seen from Table 1, the four MSE networks varied e.g. according to size; number of relationships between actors; and number of communities.

Individual centrality measures were calculated for each actor. The actors were ranked according to their centralities as is shown in Table 3, which shows an overview of the actors with highest centrality scores.

<sup>14</sup> <http://igraph.sourceforge.net/> ; <https://gephi.org/>, retrieved April 18<sup>th</sup> 2016.

<sup>15</sup> The density is dependent on the number of vertices in the network and in this study, the number of possible links were limited because of the limit on possible alters (i.e. 20 alters). Therefore one can argue that it is appropriate to reflect this in the calculation, i.e.: No. of links / (No. of vertices x 20)

	Indegree centrality			Closeness centrality			Betweenness centrality		
Mun S	Resp.	Score (no.)	Org. aff.	Resp.	Score	Org. aff.	Resp.	Score	Org. aff.
	<b>(1)</b>	16	Adm./pol.	<b>(1)</b>	0.0064	Adm./pol.	<b>(1)</b>	0.26	Adm./pol.
				(5)	0.0049	Form. ed.	(5)	0.05	Form. ed.
				(12)	0.0049	Form. ed.	(14)	0.04	Adm./pol.
Mun I	Resp.	Score (no.)	Org. aff.	Resp.	Score	Org. aff.	Resp.	Score	Org. aff.
	<b>(1)</b>	18	Adm./pol.	<b>(1)</b>	0.0115	Adm./pol.	<b>(1)</b>	0.37	Adm./pol.
	(7)	7	Form. ed.	(7)	0.0088	Form. ed.	(4)	0.11	Form. ed.
	(18)	7	Form. ed.	(37) **	0.0087	Other	(7)	0.09	Form. ed.
Mun L	Resp.	Score (no.)	Org. aff.	Resp.	Score	Org. aff.	Resp.	Score	Org. aff.
	<b>(1)</b>	9	Adm./pol.	<b>(1)</b>	0.0313	Adm./pol.	<b>(1)</b>	0.40	Adm./pol.
	(8) **	6	Form. ed.	(8) **	0.0286	Form. ed.	(8) **	0.30	Form. ed.
	(5)	4	***	(6)	0.025	Form. ed.	(6)	0.04	Form. ed.
	(3) *	4	Form. ed.						
	(10) **	4	***						
Mun U	Resp.	Score (no.)	Org. aff.	Resp.	Score	Org. aff.	Resp.	Score	Org. aff.
	<b>(2)</b>	25	Adm./pol.	(11)	0.0051	Adm./pol.	<b>(2)</b>	0.43	Adm./pol.
	(30)	14	Other	Artefact (46) ****			(11)	0.25	Adm./pol.
				<b>(2)</b>	0.0050	Adm./pol.	(30)	0.19	Other

**Table 3: The table shows an overview of the respondents with highest centrality scores in indegree, closeness, and betweenness centrality. For further description, see Paper 3. The municipalities are depicted in the rows and the centrality measures in the columns. In each column, the respondents are represented by node number in brackets in the left side (Resp.); their centrality score in the middle (Score), and their organisation affiliation in the right side (Org. aff.). Adm./pol. = Administrative and political level; Form. ed. = formal educational institution. The node numbers for the MSE coordinators are represented in bold. \*: Respondent did not want to participate in the interview; \*\*: Respondent did not respond to the interview request; \*\*\*: Respondent did not complete the SNA-questionnaire; \*\*\*\*: Artefact caused by procedure in pilot study.**

The most central actors were selected for interviews. Further description of SNA data analysis and results are presented in Paper 2 and Paper 3. The data analysis showed that the MSE coordinators had the highest centrality score in all cases but one (see Table 3). It is worth considering whether this finding was affected by the snowball approach, where MSE coordinators served as seed vertices for the sampling. In the pilot study in Mun U, the initiation of sampling differed from the procedure applied in the other three municipalities. In Mun U, the MSE coordinator was asked to appoint the most central actors from educational institutions, informal learning environments, and from the administrative and political level in the municipality. The appointed actors served as seed vertices (i.e. iteration 0) in the snowball sampling in Mun U, and not just the MSE coordinator as in the following three municipalities<sup>16</sup>. The coordinator in Mun U was also identified as most central in all centrality measures except for closeness (see Table 3). The closeness centrality score was

<sup>16</sup> The procedure was adjusted because results from the pilot study revealed a large overlap between the appointed actors and the MSE coordinator's alters and this indicated a possibility to make the sampling more efficient.

slightly higher for one other respondent (11), but the score only differed with 0.0001 from the MSE coordinator's score. This indicated that the MSE coordinators' centrality scores were not an artefact resulting from the sampling procedure. This was also supported by respondents' ability to recognise the MSE coordinators' position in the sociograms. In other words, the most central position in the sociograms seemed to align with the coordinators' position in the MSE networks (further discussion in section 4.6.2).

#### **4.4 Qualitative data collection**

All interviews were conducted as telephone interviews. The interview guides were specific for each respondent, because the interest in each respondent depended on the respondents' network positions. Therefore, individual interviews were preferred over group interviews. Telephone interviews were chosen for several reasons. I had previously conducted interviews over telephone and my experience was that it enabled me to focus on the auditory input while at the same time keeping track of the interview guide to ensure that all data were collected before ending the interview. A practical concern was also considered when choosing telephone interviews. The 22 interviews had to be conducted in a period of 1.5 months, because after completing the SNA data analysis, the summer vacation was approaching for many of the respondents and this would jeopardise the chances of making the respondents participate in the interviews. The respondents were placed in four different municipalities spread out over a substantial part of Denmark. To do face-to-face interviews would have extended the period of data collection and it would also have had an economical consequence for the project because it would have increased travel expenses significantly. Choosing telephone interviews made it possible to complete two interviews per day. This was set as the upper limit to ensure my focus in each interview. These advantages of telephone interviews were estimated to compensate for the expense of visual inputs and social interactions in a face-to-face interview.

The interview guides were designed to address the overall research question. The first part of the interview guide examined the respondents' recognition of the resulting sociogram and the data was used in the validation study (Paper 2). The second part addressed different aspects of the overall network structure and the respondents' positions in the MSE networks. The data about the respondents' positions was used to explore the centralities expressed in the MSE networks and how this affected development of science education (Paper 3). This part of the interviews included confirmatory questions about the respondents' centralities. In the cases where the respondents recognised the functions associated with their central position and hence provided a confirmatory answer, the meaning of the centrality was explored through clarifying questions. These questions concerned how the respondents used the functions associated with their position, e.g. which possibilities their position provided for their work and for development of science education in the municipality. Based on questions like these, the respondents provided information about several aspects of their central position; how their centrality found expression in their daily work; and how it affected development of science education. What was a special challenge in the interviews (and a benefit as well) was that I had knowledge about the MSE networks and the respondents' alters based on network data that I was not able to share with the respondents during the interviews. I was constantly aware of not revealing data in order to not compromise the respondents' anonymity and to avoid introducing biases that could affect the respondents' answers.

All interviews were audio recorded to secure the data and I transcribed all interviews before analysing the content.

#### **4.5 Qualitative data analysis**

Before transcribing the interviews, a set of predefined codes was generated based on the questions in the interview guide. These codes were organised in code groups that comprised a number of

codes, as illustrated in Figure 6. By use of the software Transana<sup>17</sup>, the codes were ascribed to data during the transcription process and the codes served as instruments to navigate in the extensive qualitative data.

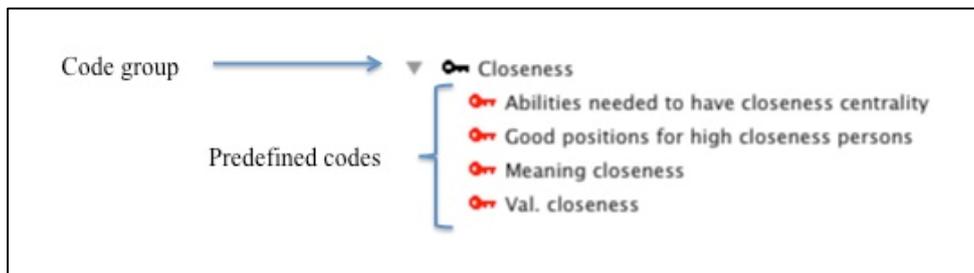


Figure 6: An example of predefined codes organised in code group in Transana.

New data-driven codes emerged during the analysis process and these codes were added to the existing ones. Figure 7 shows an example of codes that emerged during the analysis.

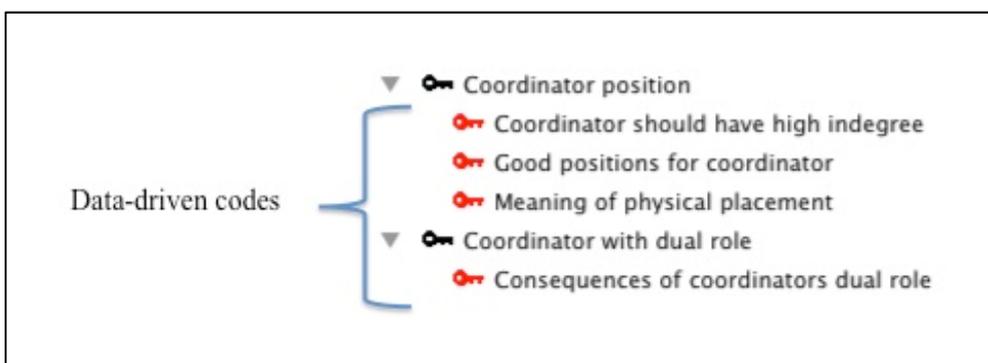


Figure 7: An example of data-driven codes that emerged during the analysis.

The predefined codes and the data-driven codes added to a total of 104 codes. This number is somewhat misleading because the codes were organized in a hierarchy as shown in Figure 6. Therefore groups of codes addressed different aspects of the same theme. After the codes were generated, they were refined to ensure that the description of each code was sound and comprehensive.

The codes were sorted and selected for further analysis based on following criteria:

- Prevalence: codes that were ascribed to the data often were selected (except when the content showed not to be relevant for the research question) (see Table 4).
- Content: codes that were ascribed to data sections describing the content of the code (i.e. not just mentioning it) were selected.
- Relevance: codes that were ascribed to data with high relevance for the research question were selected (also in cases with low prevalence)

This selection procedure resulted in 13 codes, which are presented in Table 4.

<sup>17</sup> <http://www.transana.org/>, retrieved November 4<sup>th</sup>. 2015.

Code group	Code	Prevalence
Representation	Meaning representation of organisational layers	28 (4 municipalities)
E-I-index between organisational layers	Meaning E-I-index between organisational layers	36 (4 municipalities)
Alter diversity	Meaning alter diversity persons for org. layer interplay	12 (4 municipalities)
Local vs. municipal development	Example interplay between local and municipal development	26 (3 municipalities)
Core-periphery structure	Meaning core-periphery structure	27 (4 municipalities)
Networks* in each org. layer	Importance of networks in each org. layer	18 (4 municipalities)
Betweenness	Meaning betweenness	13 (4 municipalities)
Closeness	Meaning closeness	6 (3 municipalities)
Cutpoint	Cutpoint role	8 (2 municipalities)
Network density	Considerations about network density	12 (3 municipalities)
Single person dependence	Meaning single person dependence	23 (4 municipalities)
Formal vs. informal network structure	Advantages of formal network structure	8 (4 municipalities)
Coordinator position	Good positions for coordinator	29 (4 municipalities)

Table 4: Overview of the selected codes from the total. Code group (left column), code (middle column), and prevalence (right column) are presented. Brackets denote the number of municipalities where data (ascribed with the code) originated from. vs. = versus; org. = organisational. \* The network term is used in this context to consider relationships between actors affiliated with the same organisational level in the municipality.

What characterised these codes was that they pointed to features that could be associated with mobilisation of resources. Before analysing the qualitative data, the question that guided the research was: *Which qualities in social networks are important for development of science education in Science Municipalities?* ‘Qualities’ were considered as structural features in social networks. As seen from Table 4, there was thus a focus on network level measures in the interviews. However, several of the selected codes addressed different aspects of centrality of actors: closeness, betweenness, coordinator position, alter diversity (diversity of respondents’ alters), cutpoint (vertices connecting a part of the network to the rest of the network (Hanneman & Riddle, 2011b)). It became clear during the process of analysis that based on the existing data it was more relevant to explore potentials in different network positions to understand the importance of MSE networks. Therefore the focus was placed on expression of centralities of actors in the MSE networks. This finding also resulted in adjustment to the current research question: ***How are central actors in social networks in Danish Science Municipalities affecting development of science education?***

In order to explore actors’ centralities, it was relevant to include their indegree centrality as well, even though it was not included in the codes selected at first. By including indegree, it was possible to compare this intuitive centrality measure with the more complex measures in closeness and

betweenness centrality. Therefore the centrality measures indegree, closeness, and betweenness centrality were explored (Paper 3).

I acknowledge that investigation of other centrality measures may provide additional information about how actors affect development of science education. Therefore, other centrality measures were considered as well, e.g. Google PageRank centrality. However, the qualitative data regarding this measure were unclear and the number of respondents who were able to confirm their Google PageRank centrality was low (36 %; n=4). Possible reasons explaining this could be that the wording of the confirmatory interview question was not easily understood by respondents, or that the assumptions about how this measure would be expressed in social networks did not align with reality. Therefore focus was placed on indegree, closeness and betweenness centrality. An exploration of cutpoints and alter diversity may also have provided knowledge contributing to the understanding of the importance of central actors in social networks, but the indegree, closeness and betweenness were chosen, because they were well defined and described in the literature and this provided a basis to explore their expression in the MSE networks.

#### 4.6 Methodological considerations

In this section I discuss main conditions in snowball sampling studies and the resulting consequences in the current study, as well as suggestions for adjustments to improve the methodological approach.

##### 4.6.1 Delimiting the MSE networks

When carrying out snowball sampling, it is a challenge to delimit the actors who belong to the social network in question. In network analysis, the specification of boundaries is crucial for representation of the social networks in question (Laumann, Marsden, & Prensky, 1983). This task seems straightforward if the network in question is bounded e.g. by organisational affiliation. But in cases like this study, where the population in question is not delimited beforehand because of different affiliation and involvement, the delimitation of network members can be difficult, because some actors might be more or less weakly linked to the social network. Therefore clear standards regarding inclusion and exclusion of actors in the MSE network were required.

The name generator question: *'Who within the municipality have you discussed development of science education with at least four times in the past year?'* included two criteria. The first criterion regarded the network members: all network members had to be affiliated to the municipality. The other criterion regarded the relationships between actors: the frequency of discussions had to meet the criterion of four times in the past year. I will discuss the reasons for including these criteria as a means to define the limits when mapping the MSE networks.

To start with the first criterion, a reason for only including actors affiliated with the municipality was that they worked under the same local government. This enabled a focus on municipalities as frame for science education development. Therefore, the respondents were specifically asked to name actors in the municipality (understood as geographical area under the same school administrative unit). Some of the alters named in responses turned out to be municipal external actors. These alters were removed from the network data set (as described previously).

Relationships to external actors are acknowledged as potentially important for development of science education, but because of the chosen focus stated above, these external relationships are not dealt with further in the thesis.

The frequency criterion was set after interviews with test respondents during the design of the questionnaire. The frequency for the discussions (four times in the past year) was set so as to also include actors who were involved in boards and steering groups, who tended to meet quarterly. Some of these actors could show to be relevant actors in the MSE networks. However, it was not known if all these actors were relevant in this context and therefore it was not appropriate to include

them as seed vertices. The frequency criterion was also set as a means to ensure that the actors included in the mapping of the MSE networks were frequently engaged in development of science education. However, it turned out that some respondents considered certain actors to be important for the development even though they had discussed development of science education with them less frequently than four times a year. These respondents argued that the criterion led to an underrepresentation of important actors. This meant that using the frequency criterion to select key actors might have led to missing some important network members. But it did not seem to be a general problem, because the resulting sociograms were recognised by the majority of the respondents (Paper 2). The frequency criterion included the timespan: the past year. A reason for choosing the past year was that it was the period from the official end of the SM project and to the time for data collection in the pilot study. By choosing this time frame, I had an opportunity to consider the development after the SM project end. An additional reason was that large parts of the educational system follow an annual cycle aligning with the time of data collection in the following three municipalities.

In addition to these criteria in the name generator question, an additional criterion was included in the questionnaire. The respondents were only allowed to name 20 alters and hence had to choose only the most important actors. In order to avoid the fixed choice effect (reviewed in Kossinets, 2006), the limit to the number of potential alters was also set based on interviews with the test respondents. The test respondents all stated that they would name less than 20 alters if they were to answer the questionnaire. The vast majority of respondents in the study named few actors and only few respondents named a large number (this skewed distribution of outdegree is also found in other studies (Wong, Pattison, & Robins, 2006)).

#### **4.6.2 Initiating snowball sampling**

In respondent-driven sampling, researchers have limited control over which actors are included in the sampling, except for the seed vertices (Illenberger & Flötteröd, 2012). Based on the SM evaluation, MSE coordinators were known to be central actors even before the SNA study. Therefore, they were chosen as seed vertices in the snowball sampling in the MSE networks. If mapping of the social network is not exhaustive, there is a risk that the MSE coordinators as seed vertices automatically appear more central, but because the sampling was continued to approximated exhaustion (and because the response rate was considered to be high), this possibility was considered to be low.

Snowball sampling entails a potential selection bias, since the actors identified are dependent on the names generated by the initial respondent(s). Names generated in snowball sampling is dependent on the respondents' interpretation of the name generator question (Atkinson & Flint, 2001). Therefore, it is of utmost importance that the responses in iteration 0 are valid and reliable, because this response serves as the entrance to the social network. If the name generator question is not understood correctly by the seed vertices, the alters revealed might not be members of the social network in question (false-positive alters). Data from the false-positive alters would thus not be valid. In order to ensure that the data in iteration 0 was valid and reliable, the MSE coordinators' responses were compared to existing qualitative data from the SM project, where the MSE coordinators had been interviewed each year. These interviews contained data about actors, that they had a relationship with in connection to the SM project. In this way it was possible to explore whether their responses were comprehensive. These comparisons resulted in suspicions of missing alters in two responses. The coordinators in question confirmed this suspicion and in order to ensure exhaustive responses in iteration 0, the missing alters were added subsequently. This was done to achieve high quality in the data providing the entrance to the MSE networks. One could question whether the selection of seed vertices had affected the validity of sampling, since I had prior

understanding of the coordinators' relationships and the MSE networks and since this could impose a potential bias. However, this understanding was used to achieve a more efficient sampling enabling mapping of the various actors in the MSE network. In addition, criteria for approximated saturation were introduced to ensure exhaustive mapping and the sampling complied with this procedure to ensure the validity.

#### 4.6.3 Reliability in responses

The names generated in snowball sampling are dependent on the respondents' memory (Marsden, 2011, p. 374). This issue was also addressed by one of the respondents during an interview in this study. The frequency criterion served to facilitate the respondents' memory, because the discussions had to occur within the past year. This was intended to increase reliability in responses by decreasing the risk of forgetting alters. Respondents' memory is an underlying premise of SNA studies, especially when rosters can not be used to exhaustively identify the network members, which is the case when snowball sampling proves suitable (and exactly the reason why respondent-driven sampling is chosen over saturation sampling in contexts where network members are unknown). It is possible to construct survey instruments where the name generator question is answered in a roster/free recall item, i.e. where a number of actors known to be included in the population to be sampled is listed and where respondents are able to add further alters in their response if they find the alter list incomplete (as an example see Rambøll, 2015). Rosters are especially suitable in saturation sampling, where the population in question is predetermined in the SNA study. If introducing rosters in instruments used to uncover unbounded networks, there is a risk for introducing strong biases in the sampling. The actors named in the roster can affect the respondents' understanding of which kind of actors that are most appropriate to name. The predetermined list in the roster can also impede respondents' own reflections of other alters, who fulfil the criteria in the given name generator question. In some social networks, listing all actors who could be possible alters of the respondents would result in lengthy rosters (as example, a study from Rambøll argues that using a roster would imply that the respondents should choose among 1978 possible alters (Rambøll, 2015, p. 132 (p. 3 in Appendix 2)). It is easily imagined that this could invoke respondent fatigue, when respondents were to answer. In the current study, such rosters are estimated to include up to hundreds of actors and found unsuitable for the purpose of mapping the MSE networks. Another reason for not using rosters regards the possible bias that can be introduced when presenting such lists to the respondents. If rosters were introduced in studies of unbounded networks, as e.g. the MSE networks, it would be absolutely crucial to make sure that the actors named in the roster were valid members of the social network to be studied. Otherwise, it would lead to an erroneously designation of false-positive network members, and this could lead to invalid network data. In order to ensure the reliability in responses, these are the reasons why rosters were not suitable in this study of MSE networks.

After collecting the quantitative SNA data set in the pilot study in Mun U, I presented the resulting sociogram to the science education board in the municipality. During this session one of the respondents declared not to have answered exhaustively because she was concerned about the confidentiality of the survey. This points to a potential reliability issue, which may affect some responses. If other respondents shared the same concerns, there could be a risk that they had intentionally left out some alters in their response either because they were not sure if their alters wanted to participate in the survey or because they were worried that their alter would relate them to the inquiry. If this was the case, it would have led to inexhaustive responses. In order to avoid such issues, the MSE coordinators in the following three municipalities were provided with a survey description declaring confidentiality for all responses. The coordinators were asked to distribute the survey description to relevant actors before the data collection was initiated. In this

way, some of the potential respondents had an opportunity to become aware of the survey and not feel worried about confidentiality. The coordinators were thus used as mediators to explain that the survey was recognised by relevant authorities. It was important to reassure the respondent that the information they provided would be handled with discretion and protected (Atkinson & Flint, 2001). This was done to ensure high response rates and high quality of data, which was important to for exhaustive mapping.

The instrument used in this study only included one name generator question. Because of the limitations of the online survey program used for designing the questionnaire, the respondents were asked the name generator question as many times as the number of alters they mentioned (Figure 2). It is possible that this might have given rise to respondent fatigue (Pustejovsky & Spillane, 2009) and this could have affected the reliability in data. However, the validation study showed that the resulting sociogram were recognised by the majority of the respondents and this indicated that respondent fatigue was not a systemic problem in the data collection.

The network data showed that not all relationships were reciprocated, though some degree of reciprocity might be expected based on the name generator question (including the verb 'to discuss'). Several conditions can be considered in this context. Non-reciprocated links in sociograms can result from non-exhaustive response, e.g. due to respondent fatigue or issues concerning respondents ability to remember interactions. It can also be caused by differing interpretations of the name generator question. In addition, reciprocity requires that respondents ascribe similar degree of importance to the discussions. Further research would be needed in order to explore underlying reasons for the degree of reciprocity in the network data in this study.

#### **4.6.4 Mapping social networks from partial response**

In this study, the response rates ranged from 61,8 % - 67,7 %. A high response rate decreases the risk of missing parts of the social network in the mapping and as described cautions were therefore made to ensure high response rate. There can be many reasons for lacking responses such as personal issues, lack of time, concerns about the intended use of data, doubt about how to answer the questions correctly, etc. The respondents in this study were not obliged to answer and therefore the achieved response rates are considered to be high (for comparison, another Danish SNA study including a wide range of actors involved in education achieved response rates in the order of 39, 53, 48, 45, 59 and 64 % respectively for the different respondent groups involved (Rambøll, 2015, p. 130 (see Table 1, p. 1 in Appendix 2)). However, there still remains a risk that some parts of the MSE networks were not mapped. I argue though that this is primarily a theoretical concern, because the iterative procedure enables mapping of the actors, despite lacking responses. Imagine that actor X, who does not provide a response, has a relationship with actor Y. Because actor X does not respond, there is a potential risk of missing actor Y in the social network. But if actor Y is involved in development of science education, there is a high possibility that he/she will be named by one or more of the other respondents. This means that the possibility for including actor Y in the mapping is high, even without the response from actor X. However, studies show that missing actors in social network analysis can have large effects (Huisman & Steglich, 2008; Kossinets, 2006). It can be difficult to assess the consequences of missing data in practice (Kossinets, 2006). The actors who were named by respondents in this study, but who did not respond themselves, were included in the sociograms. But further research would still be needed to explore to a larger extend the effects of the missing data in this study. At the same time, it should be acknowledged that mapping of social networks always provides approximations of the social network in question.

Because of the iterative procedure, it should theoretically be possible map the social network, even if the sampling was initiated through a seed vertex that was not degree central. However, in that case, the sampling would be vulnerable regarding response rates. If the seed vertex only has one

alter, and if that alter does not respond to the survey inquiry, the sampling ceases almost before it starts. If a randomly selected seed vertex is from a small community in the network (and is not the cutpoint) this would entail a risk of mapping only the community instead of the whole network, if the alters do not respond exhaustively to identify the cutpoint connecting the community to the rest of the network. Therefore, a similar network mapping could be achieved by using other seed vertices, but in practice, this approach would entail more risks of only mapping parts of the social network. This speaks in favour of choosing central actors when selecting seed vertices. By choosing a central actors as seed vertex (here the MSE coordinator) there is still a risk that the mapping covers certain actors in the network. The MSE coordinators were affiliated with the administrative and political level (and they all declared this organisational affiliation in the questionnaire), but they also had close connection to educational institutions (and in addition, some also had formal affiliations with these). By choosing the MSE coordinators (who were known to have relationships with actors of wide diversity) as seed vertices, the risk of mapping actors only belonging to certain organisational categories was reduced. However, there is a risk of mapping the most central actors, but since the network representations also included actors in the periphery (with only one or few alters), this did not seem to be an issue in practice. Again, the respondents overall positive recognition of the resulting sociograms, also seemed to indicate, that the sampling had uncovered a realistic approximation of the MSE networks in the municipalities.

## 5 Outline Paper 1: ‘What can we learn from the Science Municipality Project?’

### 5.1 Introduction Paper 1

The SM project (2008-2011) was a Danish development project that focused on developing science education in municipalities. The current research project took its starting point in selected Science Municipalities in the aftermath of the SM project. The paper with the title, *What can we learn from the Science Municipality project?* (originally *Hvad kan vi lære af Science-kommune-projektet?*), presents the main results from the evaluation of the SM project with a special focus on municipal structures facilitating science education development. The focus was on the macro level and not on sensemaking concerning the initiative among individual actors.

The results presented here outlines the context in which the research took place and appeals especially to actors working for development of science education in municipalities, including teachers, municipal consultants, coordinators and administrators. Therefore, the paper was aimed at and published in the Danish journal, MONA - Matematik- og Naturfagsdidaktik, and hence contributes especially to the practice field of science education.

### 5.2 Purpose Paper 1

The paper answers the broad research question: *What can we learn from the Science Municipality project?* Based on experiences from the pilot project, Science Team K, the SM project focused on establishing municipal supportive structures to facilitate and maintain development of science education in the 25 municipalities involved in the project. The paper is based on quantitative and qualitative data collected in connection to the three-year longitudinal evaluation of the SM project. Data was analysed across the municipalities to identify key elements facilitating development of science education. Five of these elements are described through exemplary cases which are detailed enough for target readers to relate the cases to their own municipal context. The elements presented here are: municipal science education coordinators (MSE coordinators), municipal science education boards, MSE coordinators’ relationships to other actors (in Danish termed ‘networks’), political foundation, and science education strategies.

The elements were found in science municipalities that experienced a positive development. The findings seemed to point to changes in municipal culture. This should be distinguished from change in specific results such as formulation and implementation of science education strategies or allocation of resources and support for science education coordinators, or even change in more quantitative measures, such as TIMMS results (which we can not fully explain). Even if changes in the culture seem to be lasting, change in such specific results are not necessarily lasting, since the order of priority of different efforts can vary. However, the elements presented in this paper were emphasised in the cases as important for lasting effect in science education and their lack in municipalities that struggled to initiate development substantiated the need for these elements. The elements pointed to two overall conditions important for facilitating development of science education in municipalities: interplay between relevant and important actors within the municipalities and political foundation. These are conditions worth keeping in mind for actors working to initiate and maintain efforts for development of science education in municipalities.

### 5.3 Connection between Paper 1 and Paper 2

Based on the results presented in Paper 1, the municipal social networks were thus considered as a crucial condition for development for science education. The overall purpose of the PhD project was to explore the processes initiated in the SM project. Therefore, it was highly relevant to

investigate these social networks and they were selected as objects for further investigation in the project.

In this introductory paper, a network definition provided by OECD was used as perspective to describe what was called 'the municipal coordinating network' (author's translation of 'det kommunale koordinerende netværk'). The amplified network description contained in OECD's definition focused on management, actions and outcome of a given social network and thus implied aspects that characterised social networks in some sustaining Science Municipalities. In the initial stage of the research project, a systematic way to approach these networks was needed in order to achieve an understanding of the mechanisms that influenced the development in Science Municipalities. Mapping of the social networks was essential for the further study and SNA was used as a means to this end. This is the centre of attention in Paper 2, where introduction of the SNA approach contributed with another network definition, which is methodologically based and pins the definition of networks down to the actors and the relationships among them. This approach serves to identify the actors and analyse relationships in the social network. This is discussed further in the following chapter serving as introduction to Paper 2.

## 6 Outline Paper 2: ‘Validation of Networks derived from Snowball Sampling of Municipal Science Education Actors’

### 6.1 Introduction Paper 2

As emphasised in Paper 1, the municipal social networks held potentials for development of science education in the Science Municipalities. In order to explore the relational structures in these networks, it was necessary to identify the actors and the relationships that connected them. No comprehensive list of actors in these networks existed because they were connected based on their different engagement in science education development and not based on organisational affiliation. Therefore, it was a main purpose to identify a methodology that could reveal and map the social networks as they appeared in Science Municipalities. The SNA approach, termed snowball sampling, served as means for this purpose, because it provided a tool to identify, analyse, and describe the structures in these undefined social networks. The network mapping built the basis for the further research and therefore, it was of utmost importance that the resulting sociograms were valid and represented the social networks in the municipalities with high accuracy. Hence, the focus in Paper 2 is the validation study conducted following the network data collection. The aim here is thus not to find an ‘ideal’ network structure in municipalities, since no such exists (though certain network structures have been considered effective or impeding in relation to certain processes, e.g. knowledge sharing, communication, and organisational change as reviewed by Daly and Finnigan (Daly & Finnigan, 2010)).

Since the paper explores the applicability and validity of the applied SNA method, it was submitted to the International Journal of Research and Method in Education and has been resubmitted after minor revisions.

### 6.2 Purpose Paper 2

The overall issue addressed in the paper is, *How can social networks of diverse actors be mapped in municipalities?* In this context, SNA contributed with a network definition, which added a useful operationalisable dimension to the network definition provided by OECD, which was used in Paper 1. These different perspectives on the network term presented in Paper 1 and Paper 2, respectively, reflect a transition in development of the research process during the project.

The municipal social networks, which were investigated in this study are termed Municipal Science Education network (MSE network). With this term, there is no focus on the coordinating function of the network (as was described in Paper 1), neither on network governance as emphasised in OECD’s network definition (also presented in Paper 1). Rather, MSE network is used as a term to describe the different actors involved in science education development in the municipalities and the relationships connecting them. The term thus describes the elements serving as basis for ‘the municipal coordinating network’ in Science Municipalities.

The mixed methods SNA study design is described in this paper and findings from the validation study are explored guided by following research question: *How do networks derived from a snowball sampling approach resonate with qualitative data from network member interviews and previous research?*

Four Science Municipalities were selected for further research and social network data from the MSE networks was collected by use of the respondent-driven snowball sampling method. This quantitative SNA study was followed by a qualitative study where selected central actors from the MSE networks were interviewed with the purpose of exploring the validity of the resulting network data. The validation study comprised two dimensions. One dimension focused on testing the network data according to central actors’ perception of the MSE network. In this dimension the network data was compared with qualitative data from interviews with these respondents. The other

dimension focused on comparing the network data with the researchers' existing knowledge of the MSE networks based on the previous evaluation of the Science Municipalities in the SM project. Based on this knowledge, hypothesis about network structures were expressed and served as a second gauge for the network data.

The first results thus presents a comparison of sociograms and central actors' perception of the MSE networks. This dimension was an attempt to reflect the representation of network data in the reality as perceived by the involved actors. In the analysis, the category 'partially recognised' was introduced in order to acknowledge nuances in the qualitative data concerning actors' recognition of characteristics of the networks. Validation studies in the field of SNA often focus on validity of the applied instrument and hence of the items used as name generator questions (Chapter 3). However, we found it interesting and relevant to validate the results from the sampling method against 'reality'. This approach builds on the assumption that the central actors were in positions, which provided them with the most comprehensive overview of the MSE network (though acknowledging that this overview will never be exhaustive). This contrasts with the ego-centred perspective of networks, where there is no assumption that actors have '*oversight of the entire network*' (Carmichael et al., 2006, p. 220). Respondents' overview of the entire MSE network should be questioned because it requires knowledge beyond their own direct relationships. It is reasonable to assume that some parts of the social networks are hidden for actors who are weakly connected, but there are reasons to believe that central actors have a more comprehensive overview of the actors in the MSE networks, because they have relationships with many actors, with diverse actors, or with other central actors.

The results showed that a considerable number of respondents recognised characteristics on network and individual level, which indicated that the sociograms had captured main structures as displayed in the 'real-life' MSE networks. When considering the number of respondents recognising their own position, it is worth to notice the possibility that some respondents could be choosing the right vertex by chance. For the respondents affiliated with the administrative and political level as example, the chance of choosing the right vertex by chance is higher, because fewer actors represented this category in comparison to the actors representing the category of educational institutions. An alternative to the approach used in this validation study could be to ask respondents to draw the MSE network and then compare their representations with the sociograms resulting from the SNA study, or to ask the questions about characteristics of the social network and let them provide their answers, before showing the sociogram from the SNA study.

Even though the condition described here should be held in mind when considering the validation, the results presented important information about the applicability of the snowball approach in municipal context. The fact that the majority of respondents considered the resulting sociograms as more or less valid representations of the MSE networks indicates the applicability of the snowball sampling. If on the other hand, the results had shown that most respondents did not recognise the sociograms, this would not necessarily invalidate the snowball sampling approach in the given context, but it could indicate certain problems with the respondents' interpretations of the visual representation of the social network. When network data is presented in sociograms, it implies a transformation of data into visual representation. Data is thus presented in an ordered form, which is to be considered as an abstraction of the social network. If respondents were not able to familiarise themselves with this representation form, it could have implication for the validation results on a wrong basis. On the other hand, if respondents showed to be unable to recognise the network representations, it could also indicate unexhaustive mapping of the MSE network, or mapping of false-positive actors or communities.

What was also interesting in this validation study was to compare network data with researchers' existing knowledge about the MSE networks. The predictions based on previous investigation of

the Science Municipalities, did not in all cases align with the results from the SNA study. This inconsistency was explained by development in the MSE networks after the last investigation in connection with the evaluation of the SM project. This indicated that MSE networks are dynamic entities as regards change in the number of actors involved. Many external contextual factors can potentially exert an influence on science education development (e.g. political agenda in local government, national regulations, funding, etc.). This can ultimately affect structures in MSE networks by leading to establishment or discontinuance of relationships between actors and resulting changes in included actors. Internal factors for individual actors (e.g. retirement and change of jobs) can also cause network structures to fluctuate. However, exploration of such correlations belongs to the theory of networks as opposed to network theory, which is the focus in the current research project (see Chapter 3 for distinction). Data from this research project can not explain connections between such external factors and fluctuations in network structure. It would require another research design and a longitudinal approach would be more appropriate to explore any correlations in this regard.

### **6.3 Connection between Paper 2 and Paper 3**

After demonstrating that snowball sampling resulted in valid representations of the MSE networks, as they were perceived by actors in the selected Science Municipalities, it was possible to explore reasons for their importance in science education in more detail. Based on the relational structures, actors are placed in different positions in the social networks and attain different kinds of centrality. Paper 3 presents an exploration of the functions associated with different centrality measures as they were expressed in the MSE networks.

## 7 Outline Paper 3: ‘Qualitative Exploration of Centralities in Municipal Science Education Networks’

### 7.1 Introduction Paper 3

Based on the mapping of MSE networks, this paper dives in to an exploration of centralities in these social networks. It focuses on functions associated with the position of central actors and seeks to explore how their centralities were expressed in the MSE networks and how it affected development of science education. This has relevance for some readers of the Journal of Research in Science Teaching and the paper has therefore been submitted to this journal.

### 7.2 Purpose Paper 3

Centrality is a measure of actors’ ‘importance’ in social network and each actor can be ascribed a certain degree of centrality depending on their network position. Different centrality measures seem to be associated with different functions and following three measures were selected in the study of central actors in the MSE networks: indegree, closeness, and betweenness centrality. The positions of actors in the MSE networks were analysed according to these three measures and the most central actors were selected for interviews. The overall issue addressed in the paper is: What functions do central actors in MSE networks have? Results from the qualitative study are presented with focus on a research question guiding the exploration of: ***‘how actors in central positions help mobilise resources in MSE networks’***.

The interviews with the central actors had two purposes. The first purpose was to assess whether they recognised the functions associated with their centrality. Data showed that the majority of the respondents did recognise the functions. The second purpose was to explore how their centralities were expressed in the MSE networks. Actors with high indegree were able to receive ideas; actors with high closeness centrality were able to distribute resources by use of other actors and also by distributing written information; and actors with high betweenness centrality seemed to connect other actors and to distribute resources between different organisations and hierarchical levels represented in the MSE network. Their descriptions thus seemed to confirm different functions for the different centrality measures. In this way, the central actors were able to mobilise resources for use in science education.

Interview questions about the functions associated with the central positions were focused on the inherent potential for the central actors to affect communication, even though other additional potentials have been described for some of these centrality measures. The name generator question in the SNA questionnaire was based on the verb ‘to discuss’ (*‘Who within the municipality have you discussed development of science education with...’*), and the selected centrality measures have been described by way of communication functions (Freeman, 1979). Therefore, it seemed appropriate to focus on communication in the exploration of the centralities as a way to investigate how exhaustively the centrality measures described the functions of the central actors in the MSE networks. In this focus lies a potential bias towards communication that may have caused the respondents to overlook other ways in which they contributed to the development of science education based on their central positions. This means that the position of central actors might have an influence on development of science education, which is not only explained by the consequences of their communication functions.

Finally, the fact that the centralities accumulated on few central actors in each MSE network seemed to accentuate their ability to mobilise resources for development of science education. At the same time it imposes vulnerability in the MSE networks, because there is a risk of critical decline in possibilities for resource mobilisation if these central actors are lost from the MSE network.

### **7.3 Connection between Paper 3 and Perspective**

The analysis of centralities in Paper 3 showed that central positions in MSE networks enabled the central actors to mobilise resources for use in science education development. This seemed to be an advantage of the social network, which can be put into perspective by the concept of social capital. This perspective will be dealt with in Chapter 9 after presentation of Discussion and Implications in Chapter 8.

## 8 Discussion and implications

In this chapter, I discuss the findings and implications from the current research project. I address how aspects of the research design affected findings and as a perspective for this discussion, I consider alternative approaches and the resulting consequences that would have followed from other designs.

Following is a short summary of the main findings in the project:

1. **Paper 1** based on the SM project evaluation:

*What can we learn from the Science Municipality project?*

From the SM project we found that political foundation and complex interactions between different actors in social networks in municipalities seemed to affect science education development.

2. **Paper 2** based on the SNA study in Science Municipalities:

*How can social networks of diverse actors be mapped in municipalities?*

Social networks of different actors in municipalities can be mapped through snowball sampling. Resulting network representations showed to be recognised by the majority of the most central actors.

3. **Paper 3** based on interviews with central actors:

*What functions do central actors have in the municipal social networks?*

Central actors mobilise resources for use in science education development.

### 8.1 What can we learn from the Science Municipality Project?

The evaluation of the SM project pointed to social networks in municipalities as important for development of science education. In relation to this, political foundation was found to be crucial for successful implementation of initiatives in the SM project. These findings provided a knowledge base for understanding development of science education involving diverse actors in social networks in municipalities and gave rise to two overall recommendations aimed at future science education initiatives: ensure political foundation and work to develop the social network of relevant actors in order to benefit from the collected resources in the municipality (Paper 1). The SM project suggested supportive structures (such as appointment of MSE coordinators, science education boards, organised networks of teachers, and science education strategy), which could facilitate development of such municipal social network in order to establish synergy between the resources available.

The findings emphasised a need for further studies to explore the underlying mechanisms that seemed to make the social networks crucial for development of science education. To some extent, the political foundation can be considered as a product of the social network and therefore focus in the current research project was placed on the networks. Paper 1 thus serves as an introduction to the context for the current research project and explains why the overall research question focuses on the MSE networks.

## 8.2 How can social networks of diverse actors be mapped in municipalities?

A snowball SNA study was completed as an attempt to map the MSE networks in four selected Science municipalities. Snowball approaches are often used to study hidden populations of shady actors (see Chapter 3), but in this study it was used successfully to identify the actors and their relationships in the previously uncovered MSE networks in Science Municipalities. These social networks were represented in sociograms, which showed to align with the MSE networks, as they were perceived by interviewed network members (Paper 2). Snowball sampling was thus found to be a feasible approach to map municipal networks comprised of different actors involved in science education development.

However, this approach showed to be demanding since it was incredible time consuming to ensure the quality of data as well as high response rates (further discussed in Paper 2 and Chapter 4). It is therefore recommended to consider cost-benefits of performing this kind of analysis, before initiating snowball sampling studies in other municipalities. The methodological experiences presented here can serve as valuable information for municipal decision-makers and actors in governing bodies when deciding whether the resources required to map such municipal networks compare favourably with the valuable knowledge about the relational structures in social networks achieved in this kind of study. In such decisions, it is worth to consider whether it is of higher relevance to identify particular parts of the MSE network relative to others, or to identify relationships involving particular actors. In that case, it might not be necessary to apply a snowball sampling approach, but the relevant knowledge might be achieved by a SNA sampling among actors, who are already known. In this way, it can be possible to use a 'light version' of the SNA study and still benefit from achieved insights into the networks.

SNA studies can reveal potential sparse relationships in social networks, e.g. between different organisations or hierarchical levels. On the other hand, it can also reveal potential redundant relationships pointing to possible resilience in the municipal network. SNA can be used to point out actors in central positions, who could be supported in order to facilitate development (further discussed in the following). This kind of knowledge can qualify decisions about future initiatives for development.

In addition to knowledge of relational structures, SNA studies can provide representations of network data in sociograms, which can be used as a means to qualify discussion about future developmental efforts for science education. As an example, the sociogram generated in Mun U was presented to the members of the science education board for a discussion of relational structures in the MSE network. During the presentation, it was emphasised that the sociogram was an illustration representing the complex social network. It was highlighted that it was not to be considered as a definitive and static representation, but as a snapshot of the dynamic social network in the municipality. If these conditions are presented along with a sociogram, this product can be used to initiate and support discussions among relevant actors about where further relationships could be established in order to facilitate development. The mapping of the social networks can be used in this way as a tool to achieve an overview of the resources being used in development as well as unexploited resources, which could be relevant to mobilise for science education. The sociogram can thus be used to engage different relevant actors in discussion about the prospects embedded in the network and which changes that could facilitate development. In addition to the board members who were the target group during the presentation in Mun U, data from SNA studies could also be used to inform e.g. science teachers about other actors involved in the development, as well as to illustrate the existence of these municipal network for political actors, who are in position to include this knowledge in decision-making. In term, this use of network data can lead to development of science education in municipalities if discussions are followed by actions from the involved actors.

### 8.3 What functions do central actors in MSE networks have?

The central actors in the MSE networks were identified based on network data. These actors were interviewed to explore how the centralities were expressed in the MSE networks. The interviews revealed that the majority of the actors recognised the functions associated with their centrality (either fully or partially) and this showed that the snowball sampling and following analysis could be used to identify actors who were central relative to others in the MSE networks.

The qualitative data enabled us to be more explicit about what characterised the central actors. The results aligned with functions described for the centrality measures in literature (Paper 3). The analysis showed that the central actors mobilised resources, e.g. by accessing and distributing different kinds of resources (e.g. information) and by connecting actors involved in science education. Data also indicated that some central actors served as link between hierarchical levels in the municipality. This emphasised the importance of diversity among the central actors' alters. It is therefore recommended that MSE networks comprise actors who have relationships to other actors in both practice and the administrative and political level.

As described, the centralities seemed to be characterised by different functions, but network data showed that in each municipality a few actors scored high in all three centrality measures. This indicated that the central actors held different functions important to science education and it seemed that the accumulation of centralities could accentuate these actors' possibilities for mobilising resources. However, the accumulation of centralities seems to cut both ways. In one way, it was indicated that actors who scored high in all three centrality measures also had multiple opportunities to mobilise resources and that these opportunities seemed to reinforce each other. But one can question whether it is possible for such a central actor to exploit all the possibilities for resource mobilisation that are associated with their position. But again, if the centralities are distributed, there would be no additive effect resulting from the accumulation. The other way round, the accumulation of centralities highlights vulnerability embedded in the MSE networks, because a loss of certain central actors could potentially have extensive consequences for the possibilities to mobilise resources for use in science education. A clear message from these implications seems to be that it is worthwhile to ensure that there is more than one central actor in MSE networks. In order to reduce the possible consequences if a central actor is lost, it is recommended that the central actors can deputise for each other. This also accounts for MSE coordinators. It would improve the resilience in the MSE network and decrease the risk of impeding resource mobilisation in the network if one central actor is lost.

The qualitative exploration of centralities thus provided information about what it means to be central in MSE networks in Science Municipalities. In most cases, the MSE coordinators were found to have the highest centrality score among the central actors. This aligned with the qualitative finding from the evaluation of the SM project, which indicated the coordinators' importance (presented in Paper 1). This study made it possible to be more explicit about *how* the central actors – and hence also the MSE coordinators - were important for the development. Since other actors than merely the MSE coordinators showed to be central as well, network analysis holds potentials to reveal positions that are important for development of science education, but which are not necessarily the focus of strategic decision-making in science education.

When the central actors are identified and when the functions associated with their network positions are articulated, it is possible to consider the support that can facilitate the actors in order to maintain their functions and benefit thereof. Different actors can provide different kinds of support (e.g. colleagues, leaders), but the overall responsibility for supporting central actors is placed on political actors (including e.g. heads of municipal administrations), who influence the establishment of conditions for the actors' work in the municipality.

At the same time the mapping, makes it easier to use the actors purposefully for development initiatives. As an example, based on SNA data one can point out actors who could efficiently distribute information based on their network position (closeness centrality), or actors who would be relevant to consult, if new ideas were needed for projects and initiatives (indegree centrality). These are examples of ways in which the knowledge achieved in this study can become actionable for future development initiatives. However, it is still an open question whether the functions associated with the central positions are unambiguous, because the accumulation of centralities complicated the task of completely separating the functions associated with each centrality measure in the study.

The focus on centralities was an attempt to investigate reasons for the importance of the MSE networks in connection to development of science education. Central positions can be considered as a result of the relational structures in the networks. Individual centrality measures can not be used as a measure of the whole network, but here identification of central actors and following exploration of the expression of their centrality made it possible to investigate resulting effects of the MSE networks in a qualitative manner.

The characterisation of centralities as they were expressed in the MSE networks can help to qualify the discussion about 'importance' of central actors in social networks. The findings point to the relevance of ensuring that municipal social networks comprise actors placed in network positions that enable them to mobilise resources for science education development. This might raise decision-makers' and central actors' awareness of the possibilities of intentional use of resource mobilisation. Alternatively, this can indicate ways in which structures in the network can be changed to improve these possibilities. In this sense, a main importance of MSE networks is establishment of possibilities for resource mobilisation.

#### **8.4 Alternative approaches**

The study was planned as an explanatory sequential design study with a focus on the quantitative part. Other approaches could have been chosen and could have added other aspects to the findings. Here I want to compare examples of alternative approaches and discuss the resulting consequences.

In the current study, qualitative data from the interviews was used to complement results from the quantitative SNA study (see Chapter 4). The weighting between the quantitative and qualitative part of the study was thus planned before the data collection with primary focus on the quantitative data. It would have been possible to plan a similar mixed methods study with an initial SNA study followed by interviews, but with a shifted focus from the quantitative data towards the qualitative data and the implications of these. However, such a shift in focus should be planned before data collection because the design and purpose influence data resulting from the different parts of the study. In order to achieve data of high quality in a study with primary focus on the qualitative data, it would require different design of the interviews and probably a different approach to analysis of the resulting data. In that case, the SNA study could have been used to select respondents for interviews (as in the current study) but without keeping the validity study in view (which was important in this study where focus was on the quantitative part). With a shifted focus, it would then have been appropriate to ask about the actors' functions in a more exploratory manner, because the functions associated with the centralities would not have been explored beforehand, as it was done here. With a qualitative focus, it would have been relevant to analyse the resulting data based primarily on data-driven codes without letting theory about centralities guide the questions, because validation of the methodological approach would not have been an objective. This could have contributed to a more comprehensive exploration of all the aspects of the central actors' functions in

the MSE networks, and not limited to the functions associated with the selected centralities. The three centrality measures were selected for further investigation in this study because they seemed to point to different potentials for the actors to affect development of science education.

Investigation of other centrality measures could also have revealed additional functions important for development of science education that are not addressed in this study.

An alternative study with primary focus on the qualitative data would be an interesting extension of the investigation of science education development in municipalities. This would allow for a relevant exploration of the content and quality in the actors' relationships. Such a qualitative approach could be supported by data from name interpreter questions in a SNA questionnaire. The SNA questionnaire used in this study included such supplementary name interpreter questions (Chapter 4), because at the time the questionnaire was designed, it was the intention also to consider the content of the relationships identified. These name interpreter questions gave rise to sociograms representing sub networks in the MSE network. The sub network had different focus and could thus be considered as different social networks contained in the MSE network. As example, the question: *"I turn to him or her for advice, when I have a new idea for improving science education"*, provided data about an advice network embedded in the MSE network. From an analysis of this kind of sub network, important information could emerge about the actors who served as advisors for others in the MSE network. It could have been possible to correlate data from certain sub network with the qualitative data about the centralities. As example it could have been interesting to correlate data from the sub network based on the name interpreter question: *"I have a connection to other people, who contribute to science education, through him or her"* with the qualitative data concerning betweenness centrality, because the analysis of the betweenness centrality measure revealed that the ability to connect other actors was a function described by some betweenness central respondents. It turned out in practice that data from the name generator question and the analysis of the centrality measures provided so much relevant information aimed at answering the research question, that it was necessary to prioritise a thorough analysis of these results, rather than to dive into the additional data provided by the supplementary name interpreter questions. If time had allowed it, this would have been an appropriate way to explore the quality of relationships and this could also have been interesting to use as a supplement if the overall focus in the study had been on the qualitative data.

In conclusion, the current weighting between quantitative and qualitative data contributed to the exploration of both the validity study of the methodological approach and the qualitative study of the central actors in the MSE network, which was intended in the study. As argued, a primary focus on the qualitative part would have required a different design of both data collection and data analysis in order to achieve highest quality of data for the purpose. Therefore, the planned weighting between qualitative and quantitative data was maintained in the data analysis, even though I acknowledge that a primary focus on the qualitative data could have added additional contributions to the findings if it had been part of the study design from the beginning.

Following from the focus in the study, there lies an implicit binary assumption in the quantification of relationships in networks following from the quantitative SNA approach. This means that a relationship is considered as existing or non-existing, even though relationships may differ according to both strength and quality. One way to measure the strengths of relationships could be to consider the number of interactions between the actors. This was done by Pitts and Spillane (Pitts & Spillane, 2009). I used another approach in order to acknowledge the differences in relationships. Based on the SNA questionnaire, only relationships that were based on continuing discussion (four times the past year) were included in mapping of the MSE networks. This construction includes the assumption that the frequency of discussions served as some kind of quality measure for the

relationships. This assumption can and should be questioned. The content and results of the discussions may be a more appropriate measure of the quality in the relationships, and could have been an objective for exploration in a study with primary focus on the qualitative data as described above. This focus would contribute with even further knowledge about how actors contributed to mobilisation of resources in science education. It is likely that some discussions contribute to development even though the frequency of the discussions falls below the lower limit defined in the name generator question. This was commented by some respondents in the study (see Chapter 4). The underlying argumentation for implementing the frequency criteria in the name generator question was that it served as a means to deselect more sporadic discussions among actors. A practical concern also spoke in favour of the frequency criteria: answering the name generator question was demanding as regards the respondents' memory of their interactions with other actors in the municipality (Chapter 4). Implementation of the frequency criteria served to facilitate the respondents' memory, because they were asked to name the actors they had had regular discussions with. Other things being equal, it is assumed to be easier for the respondents to remember the actors they have had regular interaction with, than actors they have encountered and discussed with only once the past year. This meant that without the frequency criteria, the reliability of the network data might have decreased. Therefore, the criterion was chosen, even though other criteria (or lack of criteria) might have provided other kinds of relevant knowledge.

I wish here to consider examples of alternative approaches that do not necessarily involve SNA, since other alternatives may as well have been relevant to consider. As an example, school development is a field that is being thoroughly explored and which could have offered other interesting perspectives to the exploration of science education development, because school culture is important for educational development. Since research tends to acknowledge the importance of actors outside of schools (Sillasen & Valero, 2013), another concept, that could have provided alternative perspectives, could be Networked Learning Communities (NLC) (Katz & Earl, 2010; Jackson & Temperley, 2007) (Chapter 2). In NLC there is also a strong focus on co-operation between schools and therefore this would likely have contributed with insights more specifically connected to the actors affiliated with schools.

With other research designs, additional approaches to the ones outlined here, could have been applied as well in the investigation of science education development in municipalities. In the following chapter, I wish to present a perspective to describe the advantage of MSE networks in the context of science education development in more qualitative terms.

## 9 Perspective

Provided with overviews of the MSE networks, it could have seemed tempting to correlate characteristic of the social networks with a quantitative gauge for development of science education. As argued by way of introduction in the Prologue, I did not find any measures adequate for this purpose, since neither accessible measures (as e.g. student performance or recruitment) - nor the sum of such measures - would manage to capture science education development without presenting an oversimplified picture of this complex notion (see Chapter 2 for further discussion). In stead, I present here a perspective, which serves to frame the advantage of MSE networks in development of science education in more qualitative terms. This chapter does not describe the full extent of this perspective, but outlines the idea of focusing on a superordinate term for the importance of MSE networks in science education.

The analysis of qualitative data from interviews with central actors in the MSE networks showed that their functions were characterised by resource mobilisation – functions that depended on their position in the social network (Paper 3). I argue that resource mobilisation in MSE networks implies that resources embedded in the social network are not only accessed, but are *used* with the specific aim of developing science education. This description resonates with a definition of the concept of ‘*Social Capital*’ as it is described in the context of educational studies: “*Social capital can be operationalized as the resources embedded in social systems, as well as accessed and used by actors*” (Daly, 2010, p. 4). Based on this definition, resources that are not only embedded in social networks, but also accessed *and* used by the actors, contribute to social capital.

The alignment between this definition of social capital and functions of actors in central positions in MSE networks makes it interesting to explore the applicability of social capital as a metaphor for the advantage of MSE networks in development of science education. Social capital is therefore used here as an abstraction to describe findings and resulting implications in the current study. To this end, the concept of social capital is introduced before I present my analysis of selected definitions to link MSE networks to social capital. The levels and dimensions of the concept are described and I use a selected subset of definitions to deduce the elements of social capital. Based on this, I present examples from the qualitative part of the study that illustrate how the functions of central actors can be said to contribute to social capital in the MSE networks. This leads to my description of social capital in the context of MSE networks.

### 9.1 Social capital as perspective

Many have been engaged in the conceptual clarification of social capital. As a concept, it has been used in wide contexts in the fields of social science. Bourdieu used this - among other forms of capital - to describe class formation in society caused by mechanisms involving unequal access to resources and power distribution<sup>18</sup>. He thus used social capital to explain social inequality (reviewed in Gauntlett, 2013). Coleman considered social capital as inherent in relations between actors (Coleman, 1988). As an example, he used social capital as a measure of relations between parents and children and considered social capital in families as well as in communities (here to explore the effect on high school dropout) (Ibid). Putnam is especially known for his investigation of social capital in America. Among other factors, he explored civic association and engagement (Putnam, 1995; Putnam, 2000) and in a societal context he used different types of social capital (bonding and bridging social capital) to describe homogenous groups and networks crossing social cleavages, respectively (Putnam, 2000). Social capital has also been used in the context of

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<sup>18</sup> <http://infed.org/mobi/social-capital/>, retrieved 31<sup>st</sup>. March 2016.

organisations (e.g. Hasle, Thoft, & Olesen, 2010) as well as in educational research (here involving teacher interactions Penuel, Riel, Krause, & Frank, 2009).

This introduction broadly outlines the origin and varying purposes of the use of social capital. Acknowledging this origin, I use social capital in a different context here to describe mechanisms in municipal networks in science education.

In the following, selected definitions of social capital will be presented and discussed with focus on the social networks to which social capital is linked. This aims to describe social capital in the context of MSE networks and the definitions are therefore compared and reflected in the knowledge about MSE networks achieved in the study.

Pierre Bourdieu defined social capital as: “[...] *the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition or, in other words, the membership of a group, as a collection of agents who do not only share common properties (either perceived by the observer, others or themselves) but who are also linked by permanent and useful ties*” (as cited in Waldstrøm, 2003, p. 107).

In this definition the networks (to which social capital is linked) are seen as durable, comprised of somewhat homogenous members (sharing common properties) linked through relationships that are institutionalized (to a varying degree) and permanent. When reflecting on this definition within the context of MSE networks, several discrepancies stand out and deserve a discussion.

MSE networks do not appear to be particularly durable, but rather dynamic entities of fluctuating composition, as presented in Paper 2. The relationships in the MSE networks are not necessarily institutionalised. The MSE networks also entail relationships, which can be considered as less formal in the sense that the actors are not necessarily connected by terms of employment. Therefore they are not held accountable to maintain their relationships, as applies to institutionalised relationships. The relationships are not all permanent, but some are more likely to be dynamic or temporary, since the MSE networks were found not to be considered as stable entities (see Paper 2). The actors in MSE network do not all share common properties as described for the actors in Bourdieu’s definition of social capital. They are considered as heterogeneous groups of actors with different organisational affiliation, function and main purpose. They share an involvement in municipal development of science education, but their properties resulting from their position in the MSE networks and from their affiliation and function differ, and therefore they cannot be considered as a homogenous group. In contrast to Bourdieu’s definition, MSE networks are thus considered as dynamic (rather than durable), consisting of heterogeneous actors who are connected by institutionalised or less formal relationships and affiliated to different sub-units and levels in the municipal system. Compared to the definition of networks from the field of SNA (see Chapter 3), this description is an elaborated characterisation of the actors and relationships comprising the MSE networks.

Adler & Kwon provided following definition: “*Social capital is a resource for individual and collective actors created by the configuration and content of the network of their more or less durable social relations*” (Adler & Kwon, 2000, p. 93).

This definition is a contrast to Bourdieu’s according to the notion of relationships in the network. In this definition the relationships comprising the network are not considered as permanent – as Bourdieu’s definition – but *more or less durable*. As described, this notion of relationships is concordant with the relationships in MSE networks, where some relationships could be perceived as temporarily based on cooperation between actors in a given project limited in time. Such relationships might be less durable and fading by the end of the project or they might be more

durable if the incentive in the project served to facilitate a strengthening of the relationships among the actors, which could lead to further cooperation between the actors involved. Other relationships, which are also covered in the MSE networks, are the ones formalised by organisational structures, e.g. in teacher teams in schools or in organised networks, e.g. between teachers affiliated with different schools. These institutionalised relationships might be considered more durable, since the actors are obliged to maintain their relationships, because of their appointment. But since they are not tied to their appointment, and therefore can be fired, choose to leave their appointment themselves or change function in other ways, these relationships are not necessarily more durable. In agreement with this definition, the relationships among actors in MSE networks can be considered as more and less durable.

Overall, definitions of social capital fall into two categories: definitions on individual level (node level) and definitions on network level (group level) (Borgatti & Ofem, 2010, p. 22). Definitions on the individual level focus on relationships between an individual and the individual's alters, whereas definitions on network level focus on the relationships that characterise 'the internal structure of an organization' (Adler & Kwon, 2000, p. 90). The definition by Adler & Kwon is an example of a social capital definition with focus on both the individual and the network level (here collective actors), since social capital is regarded as a resource for both individuals and the social network they comprise. I differentiate between individual and network social capital based on the types of relationships between actors. As described in Chapter 3, instrumental relationships are used to exchange resources that can facilitate achievement of an organisational goal in a social network, whereas expressive relationships are used to exchange resources that are not directly aimed at achieving organisational goals (Moolenaar & Slegers, 2010, p. 100). Social networks can comprise both types of relationships and between two given actors, both expressive and instrumental relationships can exist. Based on the name generator question in the SNA questionnaire, the focus on the MSE networks in this study is exclusively on instrumental relationships aimed at the common goal of developing science education in the given municipality. This is not to say that expressive relationships do not play a significant role in social networks in education, like for example Baker-Doyle showed for personal relationships in networks of teachers (Baker-Doyle, 2015), but here I wish to focus on social capital in the MSE network. This is on the network level and not on the individual level, as would have been more appropriate to consider, if the study explored the expressive relationships between the actors. As stated previously, I acknowledge that there is a close connection between individual and network social capital and that it is not a question of dichotomy, as the simplified presentation of levels might insinuate. Individual social capital for an actor can contribute to the social capital on the network level in MSE network and vice versa. In this sense, individual and network social capital are not mutually exclusive but interconnected concepts, but in the context of the MSE networks the focus is on the network level.

Some tend to separate social capital into (at least) two dimensions: the structural dimension and the relational dimension (Nahapiet & Ghoshal, 1998, p. 243-244). The structural dimension addresses structures of social relationships in social networks, whereas the relational dimension (also called the cultural aspect) considers the quality in the relationships between individuals, described in terms of e.g. norms or values (Moolenaar & Slegers, 2010) '*...and particularly trust*' (Van Deth, 2003, p. 80). The two dimensions are not absolutely separated (Nahapiet & Ghoshal, 1998) but can be considered as interdependent characteristics (Van Deth, 2003). Nahapiet & Ghoshal have described a third dimension of social capital, the cognitive dimension, but since this dimension applied especially to their investigation of intellectual capital, it is not described further in this context.

Robert D. Putnam's definition of social capital reads: "*social capital refers to connections among individuals - social networks and the norms of reciprocity and trustworthiness that arise from them*" (Putnam, 2000, p. 19) and thus includes both the structural dimension (connections among individuals) and the relational dimension (norms of reciprocity and trustworthiness) of social capital. The name generator question used in this study served to map the relationships (connections) among actors. The analysis was centred round data resulting from this question and the focus in the study was placed on the structural dimension. Name interpreter questions could have been used to address aspects of the relational dimension and if this dimension had been in focus, the qualitative interviews could also have been focused to shed light on norms, values, or trust to dive into this aspect of social capital. However, this lies beyond the limits of the current study and would be an interesting aspect for future research.

According to Svendsen & Waldstrøm, James S. Coleman defined social capital as "*people's ability to co-operate in achieving a common goal*" (Svendsen & Waldstrøm, 2012, p. 311). In this definition, the structural dimension of social capital lies implicit in the notion of 'ability to co-operate'. In order to co-operate, there need to be relationships between the co-operating actors. Coleman's definition looks one step ahead of the relationships and into the possible results of the relationships, namely in the notion of 'achieving a common goal'. In the MSE networks, the members' co-operations had form of discussions about their common goal, i.e. development of municipal science education. This might be the only goal the actors in MSE networks shared, since they had different affiliations, different functions, and hence different primary agendas in their work in the municipality. Because the members were affiliated with different organisations placed on different hierarchical levels in the municipal system it was appropriate to lean on a version of social capital termed '*communal social capital*'. Communal social capital can be defined as "*the benefits that accrue to the collectivity as a results of the maintenance of positive relations between different groups, organization units, or hierarchical levels*" (Ibarra, Kilduff, & Tsai, 2005, p. 360). This definition is based on the assumption that relations between individuals (in different sub-units) promote collective benefits to the entire network. This aligns well with social capital in regard to MSE networks, because the focus is not on benefits for individual actors but on how they can use the functions associated with their network position to benefit the overall aim of the social network. Relationships are often reciprocated (Wellman, 1983). In organisations, this fact can be a double-edged sword when considering relationships between actors affiliated with different organisations. Such inter-organisational relationships can provide an organisation with important resources e.g. inspiration and knowledge. On the other hand, because of the reciprocity of interpersonal relationships, inter-organisational relationships can also lead to a leak of resources e.g. in the form of information to competing organisations (Waldstrøm, 2003), which in term can lead to a decline in the organisation's social capital. In the context of MSE networks, this potential disadvantage of inter-organisational relationships is not considered as a relevant issue, because the involved organisations and levels often served different overall purposes and were thus not considered as rivals.

The overall focus in this chapter is on the structural dimension of social capital on the network level in MSE networks. However, the structural dimension is also connected to the individual level in networks, because the relational structures leaves actors in positions attached with different centralities (Paper 3), which seemed to affect social capital on network level. It is therefore interesting to consider how individual actors can contribute to social capital on a network level. Even though the relational dimension of social capital should not be ignored, what is presented here is a focus on the structural dimension as an attempt to consider how results of relational structures

in social networks can contribute to social capital. In order to pursue this aspect, social capital is explored in the following to set out the elements comprising the concept more explicitly.

## 9.2 Elements of social capital

The discussion of the selected definitions presented in the first part of this chapter showed that authors define social capital in slightly different ways and with a differing focus on levels and dimensions. As an attempt to clarify what this elusive concept covers, I made a close analysis of a selected subset of definitions (provided by Adler and Kwon) by dissecting the concept to identify the substance and the effect (substance and effect of social capital are also considered in Adler & Kwon, 2002). The result of my analysis is presented in Table 5 and serves as foundation on which the substance and effect is defined as elements of social capital.

Definition of social capital	Substance	Effect
“a resource that actors derive from specific social structures and then use to pursue their interests; it is created by changes in the relationship among actors” (Baker 1990: 619)	Social structures/ <b>relationship</b>	<b>Resource</b>
“an individual's personal network and elite institutional affiliations” (Belliveau, O'Reilly, & Wade 1996: 1572)	Personal network	-
“the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition” (Bourdieu 1985: 248)*	<b>Relationships</b>	Aggregate of actual or potential <b>resources</b>
“the sum of the resources, actual or virtual, that accrue to an individual or a group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition” (Bourdieu & Wacquant 1992: 119)	<b>Relationships</b>	Sum of actual or virtual <b>resources</b>
“the number of people who can be expected to provide support and the resources those people have at their disposal” (Boxman, De Graaf, & Flap, 1991: 52)	People	<b>Resources</b>
“friends, colleagues, and more general contacts through whom you receive opportunities to use your financial and human capital” (Burt 1992: 9)*	Contacts (e.g. friends and colleagues)	Opportunities to use your financial and human capital
“the process by which social actors create and mobilize their network connections within and between organizations to gain access to other social actors' resources” (Knoke 1999: 18)	Network connections	<b>Resources</b>
“the ability of actors to secure benefits by virtue of membership in social networks or other social structures” (Portes 1998: 6)	Membership in social networks	Benefits
“the web of cooperative relationships between citizens	Cooperative	Resolution of

that facilitate resolution of collective action problems” (Brehm & Rahn 1997: 999)	<b>relationships</b>	problems
“Social capital is defined by its function. It is not a single entity, but a variety of different entities having two characteristics in common: They all consist of some aspect of social structure, and they facilitate certain actions of individuals who are within the structure” (Coleman 1990: 302)	Social structure	Actions
“Social capital can be defined simply as the existence of a certain set of informal values or norms shared among members of a group that permit cooperation among them” (Fukuyama 1997)*	Group (with cooperating members)	Values or norms
“a culture of trust and tolerance, in which extensive networks of voluntary associations emerge” (Inglehart 1997: 188)	Culture	Voluntary associations
“those expectations for action within a collectivity that affect the economic goals and goal-seeking behavior of its members, even if these expectations are not oriented toward the economic sphere” (Portes & Sensenbrenner 1993: 1323)	Collectivity	Affection of economic goals
“features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit” (Putnam 1995: 67)	Social organisations	Benefit
“those voluntary means and processes developed within civil society which promote development for the collective whole” (Thomas 1996: 11).	Society	Development
“naturally occurring social relationships among persons which promote or assist the acquisition of skills and traits valued in the marketplace... an asset which may be as significant as financial bequests in accounting for the maintenance of inequality in our Society” (Loury 1992: 100).	Social <b>relationships</b>	Skills and traits
“the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit. Social capital thus comprises both the network and the assets that may be mobilized through that network” (Nahapiet & Ghoshal 1998: 243)	<b>Relationships</b>	Sum of actual and potential <b>resources</b>
“the web of social relationships that influences individual behavior and thereby affects economic growth” (Pennar 1997: 154)	Social <b>relationships</b>	Economic growth

“the set of elements of the social structure that affects relations among people and are inputs or arguments of the production and/or utility function” (Schiff 1992: 160)	Social structure	Inputs or arguments
“the information, trust, and norms of reciprocity inhering in one's social networks” (Woolcock 1998: 153)	Social networks	Information, trust, and norms of reciprocity

**Table 5: The table shows an overview of selected definitions of social capital (left column), and analysis of the substance (middle column) and the effect of social capital (right column). The selected definitions presented in left column are taken from Table 2 in (Adler & Kwon, 2002, p. 20). In the cases where Adler & Kwon presented two definitions from the same author(s), I included only one of the definitions in this table. In these cases the definition is denoted by \*. The middle and the right column show my identification of substance and effect as they appeared in each definition. The overall elements for substance and effect are written in bold. For further discussion, see text.**

The definitions in Table 5 present a diverse picture of social capital. Based on the analysis in this table it is seen that the notion of substance and effect in social capital is not consistent throughout the definitions. Some of the definitions focus entirely on the structural dimension (e.g. Baker 1990: 619; Knoke 1999: 18; Nahapiet & Ghoshal 1998: 243), whereas others include the relational dimension (e.g. Bourdieu 1985: 248; Bourdieu & Wacquant 1992: 119; Fukuyama 1997; Putnam 1995: 67; Woolcock 1998: 153). This differing focus affects the notion of substance and effect in the definitions.

When considering the analysis presented in Table 5, notions of substance includes following: ‘social structures’/‘relationships’/‘network connections’; ‘people’/‘contacts’; and ‘network’/‘social organisations’/‘society’/‘group’. This calls for a clarification. ‘Social structures’/‘relationships’/‘network connections’ are all synonyms for the relationships between actors, whereas ‘people’/‘contacts’ are synonyms for the actors, who are linked to each other through the relationships. ‘Network’/‘social organisations’/‘society’/‘group’ are synonyms for the social network that comprise the actors *and* the relationships between them, as follows from the definition of social networks in SNA (see Chapter 3). These aspects all come down to the relationships between actors in social networks and therefore I use relationships as the simplified expression for substance.

Turning the focus from substance to effect of social capital, it is seen from Table 5 that the general notion of effect is ‘resources’/‘benefits’ of various kinds. As example, some of the definitions set out the resources more explicitly e.g. in an economical sense. One definition describes the effect as actions. To exemplify this in the context of MSE networks, teaching is an action considered as a resource. One definition describes the effect of social capital as skills. In the context of MSE networks, e.g. teaching skills are considered a resource. These examples show that the definitions points to varying aspects of effect, but they share a focus on resources.

Summarising the analysis presented in Table 5, it seems that even though the formulation and focus differ in the definitions, the concept of social capital can be pinned down to two elements: relationships comprising the substance and resources comprising the effect of social capital.

Different network structures have been linked to social capital in the field of SNA (Burt, 2000). However, operationalisation of the concept in social science remains challenging because of its level of abstraction (Van Deth, 2003). In the following I wish to focus on the substance and effect of social capital as an attempt to operationalise the concept and consider contribution to social capital in MSE networks.

### 9.3 Central actors increase social capital by mobilising resources

In this section, I point out examples from the qualitative study to describe how central actors contributed to social capital in the MSE networks ultimately leading to science education development. The examples presented here involved actors who scored high on indegree, closeness, as well as betweenness centrality. These actors were chosen for this purpose because the accumulation of their centralities seemed to accentuate their abilities to mobilise resources. The examples are not included here to describe their centrality (this is explored in Paper 3), but included because they represent illustrative examples of the applicability of social capital as a concept to describe the importance of MSE networks in development of science education.

The positions of central actors in MSE networks result from these actors' relationships with others in the social network. The central actors had access to different kinds of resources because they had relationships with many different actors in the municipalities in different contexts, e.g. municipal teachers, school leaders, actors in informal learning environments, in the municipal administration, or in enterprises. During the interviews, the central actors mentioned a variety of examples to illustrate the resources they distributed to others, e.g. ideas for science teaching, know-how, inspiration, practical project information, course information, news from science actors outside the municipality, information about resources as informal learning environments in the municipality (e.g. a water tower and nature school), fundraising possibilities, and teaching materials. In this way, central actors created access to resources for others. They were able to mobilise resources by distributing them to relevant actors, who could make use of them for development of science education. Their relationships thus enabled resource mobilisation of various kind and social capital serves here as a broad term to describe the relational structures and the resulting resource mobilisation in the social network.

#### 9.3.1 Mobilisation of resources as information, knowledge, and ideas

From the interviews it showed that the central actors had access to knowledge from many different sources. One of these actors explained that she had a '*knowledge function*', as she called it, and was able to answer when e.g. teachers phoned her and asked about many different aspects of science teaching, such as access codes for different subscriptions, teaching materials as books, or how many pupils were intended to comprise a group during the national science tests. These resources could be said to be contributing to the development of science education as she shared her knowledge with teachers. By sharing the knowledge, resources could be mobilised, if the other actors made use of them, e.g. gaining access to books.

In addition to mobilise resources themselves, some central actors also mobilised resources by using their alters intentionally to distribute resources further to actors more distant from themselves (a feature described for closeness centrality in Paper 3). This was the case when they distributed resources through teachers they had a relationship with and when the teachers then distributed the resources further to their colleagues in the schools. A central actor also explained that she distributed resources through members of the municipal science education board. By using their alters, the resources were made accessible to even more actors, than just those, whom the central actor had a relationship with. One central actor described how she distributed resources on the initiative of the actors she had relationships with. She explained that actors in the local museum and local nature school used her to distribute information. If they wanted to spread information they sent them to her, because she was able to distribute them further. In this way, she facilitated mobilisation of resources from other actors in the municipality.

These examples show that central actors contributed to social capital in the MSE networks by using their relationships to mobilise different resources for use in science education. Resources in form of

information were in large part distributed through digital media. In addition, some central actors also explained that they distributed resources in other contexts. One explained how he inspired different actors by visiting schools, informal learning environments, and before- and after-school care to explain and show how others worked with science. In this way, information and knowledge were also shared in physical meetings with actors working with science education in different settings. He elaborated and told that in these settings he contributed with ideas. Ideas seemed to be a type of resource that played an important role in the MSE networks. For example, two actors said that they were involved in discussion with actors from informal learning environments and helped them generate ideas for new science projects. This illustrated that the actors mobilised resources by being involved in generation of new ideas.

Some central actors also distributed resources to others who were not directly involved in science education, but who could benefit from gaining an access to resources used in science education. As an example, one central actor shared information with the other consultants in the municipal administration, who distributed this information further to actors who made use of the information in other contexts. Another central actor told that apart from distributing resources to the other municipal consultants, she also used information that she had access to through her relationships with the consultants, and distributed these resources to actors involved in science education. This example showed that she mobilised resources originating from science education, but also resources originating from other contexts that were not directly linked to science education and in this way she increased the social capital through the relationships. It thus seemed that central actors increased social capital not only in the MSE network but throughout the municipality by using the diversity among their alters to mobilise resources in various settings.

These descriptions serve to exemplify how the relational structures in the MSE network enabled the central actors to contribute to social capital.

### **9.3.2 Mobilisation of resources as funding, projects, facilities, and materials**

Central actors' relationships to the administrative and political level seemed to be important for their possibilities to mobilise resources in form of funding. This was illustrated when one actor explained, "*when I have a good relationship to them [politicians], I have not yet been refused. To have that political relationship is important*". Because political decisions also consider funding, this could be interpreted as a way to mobilise this kind of resources. This was supported by another central actor, who explained: "*By now I know many niches of the municipality – also organisationally speaking – I have become good at finding cash.*" This showed that the actor used her knowledge about the municipal organisation to mobilise funding. As described, this required a thorough knowledge about the municipal organisation and as she indicated this is not possible to acquire over night, but comes with experience.

Educational projects and events are examples of other resources mobilised by central actors in the MSE networks. One actor explained that it was easy for her to repeat already known projects but also to start new initiatives, because she had relationships with many different actors. Another actor told that sometimes he initiated events, which were developed further by the participants:

*"However, there are events where I initiate things and then they catch the ball and things happen which I am not involved in."* The actor, who visited different learning environments, explained that he brought papers or links about science events, which he encouraged the other actors to participate in. By doing this, others became aware of the resources and were thereby able to use them as well. Other resources, that were mobilised, counted materials and learning environments. During an interview, a central actor told that he had invited teachers for the opening of a new nature school in the municipality. In this way, he facilitated actual use of the nature school as resource in science teaching. As long as teachers in the municipality were largely unaware of the new nature school,

they were unable to use it in their science teaching. By inviting the teachers to the opening, he thus facilitated mobilisation of the resource comprised by the nature school.

These are examples where central actors were involved in mobilisation of funding, projects, facilities, and materials. This was facilitated through their relationships and can be interpreted as contributions to social capital in the MSE networks ultimately affecting science teaching.

### 9.3.3 Mobilisation of resources by connecting actors

Some central actors contributed to social capital indirectly by connecting other actors and in this way change the relational structure to better facilitate mobilisation of resources. Some central actors established relationships between different actors in science education boards or between teachers, e.g. in organised networks of teachers in the municipality or in a peer-to-peer teaching project for pupils, which was described as another example. The central actors were very clear when they explained the results of connecting teachers in these various contexts. They told that teachers talked about their practice and their thoughts about science teaching. The discussion between teachers in these contexts enabled them to test their ideas among peers and get new perspectives on their teaching practice, as the central actors explained. In this way the central actors facilitated mobilisation of resources among teachers by creating setting where relationships were established between them. The central actors' contribution to social capital in this context is indirect in the sense that they connected the teachers and this paved the way for teachers to share ideas and hence to mobilise resources for use in science education.

## 9.4 Social capital in MSE networks

In the examples described in the previous section, contributions to social capital are empirically based in the sense that the contributions were expressed as mobilisation of resources brought about through the central actors' relationships in the social network. In this sense, social capital served as a means to consider and structure the ways in which the central actors contributed to development of science education as a result of their network position. Social capital thus provided a concept to understand important mechanisms in MSE networks. Other factors also influence science education development, e.g. political agendas, municipal economy, and demographics. However, social capital is decisive for the way these other factors can be managed and thus for the effect (facilitating as well as impeding) they may exert on the development.

Regarding social capital, '*...the level of abstraction remains so high that virtually no definite conclusions or implications for operationalizations can be deduced.*' (Van Deth, 2003, p. 81). As is clear from this chapter, social capital has been used in many different research fields and for different purposes and therefore has been defined in different ways and is therefore subject to some degree of conceptual ambiguity. From the analysis in Table 1, the element of social capital is boiled down to the substance in form of relationships and effect in form of resources. In order not to let the variations in the large number of definitions confuse the concept as it applies in MSE networks, I wish to present a description of social capital in this context that is based on the two elements:

*Social capital in MSE networks is considered as the relational structures that facilitate mobilisation of resources used for development of science education in the given municipality.*

This description is not in sharp contrast to existing definitions, e.g. "*...Social capital thus comprises both the network and the assets that may be mobilized through that network*" (Nahapiet & Ghoshal, 1998, p. 243). However, it serves to emphasise how social capital can be used as a metaphor for the advantage of MSE networks in science education, because it sets out explicitly that the resources that are mobilised as a result of the relationships are aimed at development of science education.

Bankston and Zhou emphasise that social capital '*does not consist of resources*' but '*of processes of social interaction leading to constructive outcomes*' (Bankston III & Zhou, 2002, p. 285). In this sense, the 'constructive outcome' in the MSE networks is resource mobilisation.

The relational structures determine the resources accessible in a given social network and therefore ultimately determine the possible extent of social capital. In this perspective, contributions to science education result from mobilisation of resources through relationships between actors in the social network. Social capital therefore helps to add a normative dimension by offering a focus for the overall objective in future initiatives aimed at facilitating and supporting development of science education. This focus directs attention to the potentials in efforts increasing social capital in order to facilitate mobilisation of resources for development of science education.

## 10 Conclusion and future research

This project presents a study exploring the social networks of science education actors in four Danish Science Municipalities. The evaluation of the Science Municipality project indicated that these networks were important for development of science education (Paper 1). These results provided the background for the overall research question in this study: ***How are central actors in social networks in Danish Science Municipalities affecting development of science education?*** The following issues were addressed in order to answer the research question:  
*How can social networks of diverse actors be mapped in municipalities?* (Paper 2)  
*What functions do central actors in MSE networks have?* (Paper 3)

In order to map the existing municipal science education networks (MSE networks) in the Science Municipalities, a mixed methods SNA approach was applied (Paper 2). Use of snowball sampling provided quantitative network data and the following interviews provided qualitative data from selected network members. The snowball sampling approach enabled mapping of the MSE networks in the four municipalities by identifying the different science education actors and revealing the relationships between them. Qualitative data was used to study the validity in order to ensure that the resulting network representations (sociograms) aligned with the existing MSE networks. The validation study showed that the sociograms were coherent with network members' perceptions of the MSE networks to great extent. In conclusion, snowball sampling was found to be an applicable method to map social networks of 'hidden' actors involved in science education development in municipalities. This finding contributes to the future use of SNA studies in educational research.

The SNA study showed that in each MSE network there were a few highly central actors (Paper 3). The interviews with these actors were used to explore how they affected development of science education. The results indicated that central actors were able to access and distribute various kinds of resources to different actors involved in science education. This occurred in both physical meetings and through distribution of written information. Some central actors were able to connect relevant actors, e.g. by arranging meetings and by helping them become aware of each other. Some also served as link between policy and practice. This is important and worth to take note of since connections across organisational levels can be a challenge but holds potentials for science education as regards coordination of resources and initiatives aimed at development. Overall, the results indicated that the position of central actors in MSE networks enabled them to affect development of science education by mobilising resources for use in science teaching and by mobilising resources affecting conditions for science teaching. In addition, the accumulation of centralities in certain positions in the social networks seemed to accentuate the actors' ability to mobilise resources.

The findings from this research project pointed to the crucial functions of central actors as regards utilisation of resources in the municipalities. If these functions are not filled, it imposes a risk of wasting resources relevant for science education development. It demonstrates the importance of MSE networks by acknowledging that actors in central positions (resulting from the relational structures in these networks) play important roles in development of science education and should be supporting in order to facilitate the development. This can contribute to the knowledge base for governing bodies and decision-makers in municipalities to make informed decisions aiming at future development initiatives in science education.

Turning the focus to Astra, which hosted this PhD project, the results provided insight in the complexity of municipal social networks, which are objects for projects in Astra's municipal

initiative. This pointed to the potentials for development of science education that are embedded in these municipal networks and thus serves as a recommendation for Astra to maintain and develop the municipal initiative with the purpose of strengthening science education in Denmark. The SM project has been a source of inspiration as regards educational development in some international contexts<sup>19, 20</sup>. As an example, the government in Norway has initiated a Science Municipality project involving 34 municipalities<sup>21</sup>. The result from the current research project therefore seems to be relevant in an international perspective as well.

Based on the findings, there are several aspects, which appear to be relevant for future research. One aspect is the question of content and quality of relationships in municipal social network, i.e. the importance attached to the quality of different relationships in relation to mobilisation of resources. This is relevant to explore in future qualitative studies.

Another interesting aspect is how awareness of the importance and functions of central positions in MSE networks can affect efforts aimed at science education development. Future studies could explore how raising central actors' awareness of the functions associated with their positions in the social networks might help them fulfil those functions.

A last interesting aspect, which could be relevant to explore, is the development of relational structures in MSE networks. Findings in Paper 2 indicated that the MSE networks were dynamic in the sense that the number of actors seemed to fluctuate over time. Carrying out follow-up SNA studies in the selected municipalities could be an occasion to explore the development of MSE networks in further detail. If such a longitudinal SNA study was complemented with qualitative studies of contemporary changes concerning other factors in the municipalities (e.g. political agendas, turnover of key actors, reallocation of municipal funding), it could provide important knowledge about factors that might influence development of these municipal social networks and hence science education development. Such future research could contribute even further to the field of SNA in educational studies because it would add a temporal dimension to the results achieved in this project. In addition, it could inform the future work of municipal decision-makers, Astra, and other governing bodies involved in educational development projects, by pointing to factors, which could be adjusted in order to facilitate development.

Summarising, the results provided knowledge about the importance of MSE networks by describing functions of central actors resulting from their network positions ultimately depending on the relational structures in the MSE networks. This offers an important contribution to the discussion about mechanisms involved in development of science education.

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<sup>19</sup> [http://pe2020.eu/wp-content/uploads/sites/15/2014/02/Public\\_Engagement\\_Innovations\\_H2020-2.pdf](http://pe2020.eu/wp-content/uploads/sites/15/2014/02/Public_Engagement_Innovations_H2020-2.pdf), retrieved April 13<sup>th</sup> 2016.

<sup>20</sup> [http://ec.europa.eu/research/swafs/pdf/pub\\_science\\_education/KI-NA-26-893-EN-N.pdf](http://ec.europa.eu/research/swafs/pdf/pub_science_education/KI-NA-26-893-EN-N.pdf) (reference 92), retrieved April 13<sup>th</sup> 2016.

<sup>21</sup> <http://www.udir.no/Lareplaner/Forsok-og-pagaende-arbeid/realfagskommuner/>, retrieved April 13<sup>th</sup> 2016.

## 11 Afterword

Now at the end of the PhD project, it is worth once again to envision the picture with the steaming locomotive in the desert paving its way towards the torn tracks. Did I succeed in building new tracks ahead of the locomotive to keep it on track? I suspect not – but my research managed to place a main sleeper for the track in front of the locomotive. It provides an important building brick for the future construction to keep the train on track. Literally speaking, this research provides relevant knowledge about conditions important for science education development in municipalities.

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# Hvad kan vi lære af Science-kommune-projektet?



Ane Jensen,  
Dansk Naturvidenskabs-  
formidling og Institut for  
Naturfagernes Didaktik



Jan Sølberg,  
Institut for Naturfagernes  
Didaktik, Københavns  
Universitet

**Abstracts:** En fjerdedel af landets kommuner indgik i Science-kommune-projektet, som blev afsluttet i foråret 2011. Kommunerne havde udvikling af naturfagsområdet som fokusområde, og de vigtigste erfaringer fra projektet præsenteres her. Ud fra en analyse af data indsamlet gennem hele projektet stiller vi skarpt på fem cases og bruger dem til at understrege to vigtige elementer som vi kan lære af fra Science-kommune-projektet. Elementerne er en udbredt politisk forankring af naturfagsindsatsen og etableringen af et koordinerende netværk i kommunen. Disse to elementer syntes at være gennemgående træk fra de Science-kommuner som oplevede forandringer i måden man arbejdede med naturfagene på i kommunen.

*One quarter of Denmark's municipalities was included in the Science-municipality project, which ended in the spring 2011. The municipalities focused on developing science education in a broad sense. Key lessons from the project are presented here. From an analysis of the data material collected throughout the project, we focus on five cases and use them to emphasize two important elements, which we can learn from the Science-municipality project. The elements are widespread political foundation of the science efforts and the establishment of a coordinating network in the municipality. These two elements appeared to be consistent features of the Science municipalities that experienced positive improvements in the way they worked with science in the municipality.*

## 1. Indledning

Science-kommune-projektet (2008-2011) involverede en fjerdedel af landets kommuner og en tredjedel af landets skoleelever. Det var et af mange nyere udviklingsprojekter som havde til formål at fremme børn og unges interesse for naturfag og teknik. Forud for Science-kommune-projektet havde man i det lokale udviklingsprojekt *Science Team K* (2003-2006) fundet at en af de vigtige faktorer som påvirkede den langsigtede

udvikling på naturfagsområdet, var at få forankret udviklingen i kommunen. Ved afslutningskonferencen for Science Team K i 2006 formulerede daværende undervisningsminister Bertel Haarder visionen:

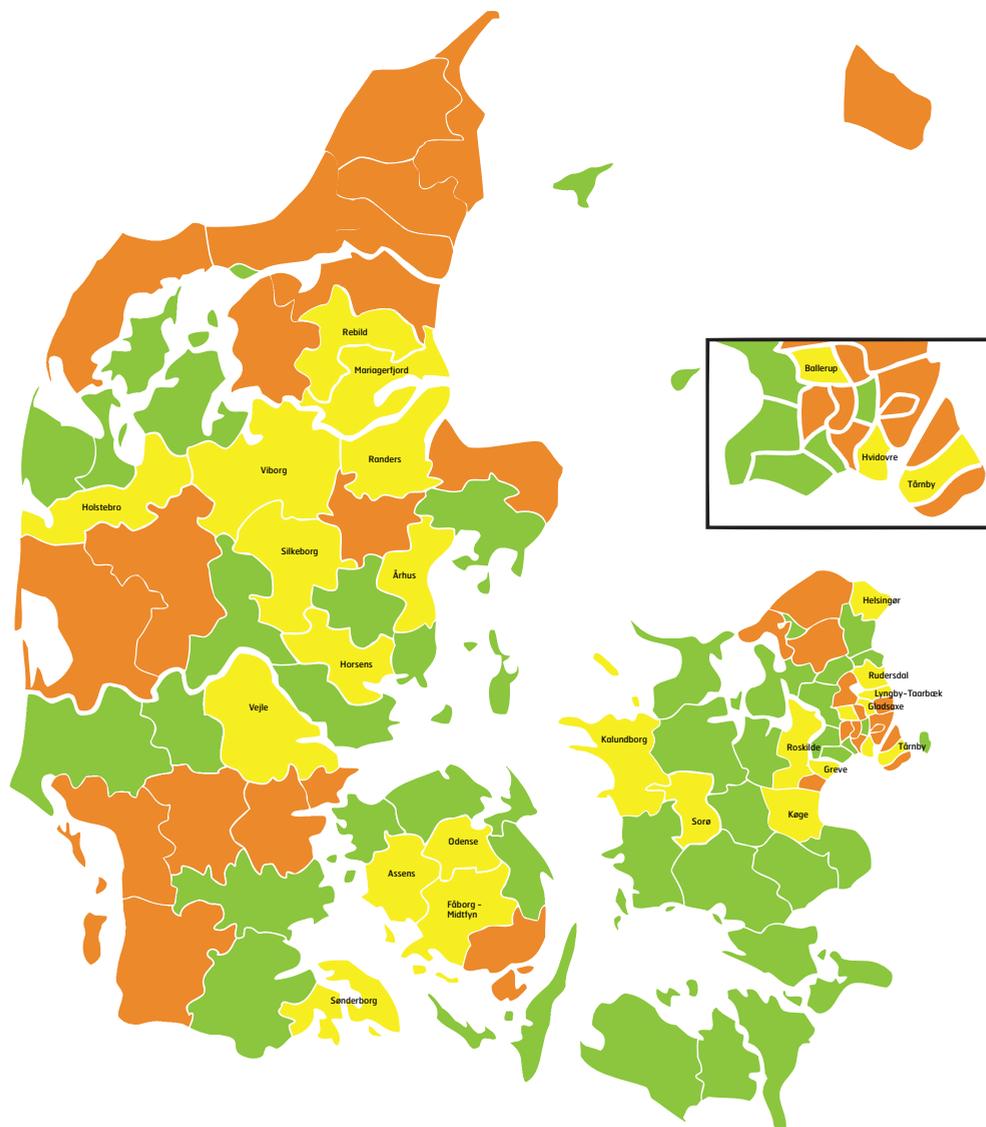
“Hvad om der blandt de kommende 98 kommuner blev en konkurrence om, at 25 af dem kunne kalde sig Science-kommuner? Det kunne virkelig give naturfagsundervisningen et skub.”

Baseret på erfaringerne fra Science Team K valgte Undervisningsministeriet efterfølgende finansielt at støtte en opskalering af projektet til Science-kommune-projektet hvor målet var at få 25 kommuner (se figur 1) til at engagere sig i naturfagsindsatsen kommunalt. Kommunerne i projektet blev kaldt “Science-kommuner”, hvilket principielt betød at man i kommunen som helhed havde valgt at sætte udviklingen af vilkårene for naturfagsundervisningen på tværs af uddannelseskæden på dagsordenen.

Danmark har dog ikke været enestående med hensyn til politiske satsninger på naturfagsområdet<sup>1</sup>. Andre lande er gået forud med foregangseksempler rettet mod at øge interessen for naturfagene. Særligt i Holland havde man været meget opmærksom på det voksende problem med den utilstrækkelige ressource af naturvidenskabeligt uddannede kandidater, og derfor gennemførte det hollandske ministerium for uddannelse, kultur og science (Dutch Ministry of Education, Culture and Science) “The delta plan” som var en storstilet national satsning for at rekruttere børn og unge til Betafagene, som de naturvidenskabelige fag kaldes i Holland. Resultaterne fra Holland peger på at inddragelsen og koordinationen af politiske kræfter, private virksomheder, interesseorganisationer og lokale uddannelsesinstitutioner kan være med til at føre til de nødvendige langsigtede forbedringer i naturvidenskabelige fag (deBoer & Steen, 2006). Tanken om at inddrage det omgivende samfund i naturfagsundervisningen har da også været fremhævet i en række ministerielle rapporter og handleplaner med fokus på naturvidenskabelige uddannelser i Danmark (Andersen et al., 2003; Andersen et al., 2006; Undervisningsministeriet, 2008).

Science-kommune-projektet fokuserede på etableringen af kommunale strukturer til fremme og fastholdelse af en positiv udvikling på naturfagsområdet. Erfaringerne fra Science-kommune-projektet har bekræftet at der kan være store udviklingspotentialer i en målrettet kommunal koordination af de mange aktører (hvad enten det drejer sig om formelle, uformelle, private eller offentlige aktører) som på hver deres måde beskæftiger sig med naturfaglige problemstillinger (Sølberg, 2009; Søl-

1 Her refereres til naturfagsområdet som de *undervisningsfag hvori naturvidenskabelige problemstillinger og emner leverer hovedparten af indholdet*, jf. Fremtidens Naturfaglige Uddannelser (<http://pub.uvm.dk/2003/naturfag/html/chapter04.htm>). I det følgende bruges samlebetegnelsen “naturfagene” for at dække over alle interessenter som har en berøring med disse fag.



**Figur 1.** Science-kommuner anno 2011 markeret gule.

Kilde: [www.formidling.dk/graphics/DNF/skole/Science-kommuner/54kommuner201009.pdf](http://www.formidling.dk/graphics/DNF/skole/Science-kommuner/54kommuner201009.pdf).

berg, 2010; Sølberg & Jensen, 2011). Den overordnede konklusion på evalueringen af Science-kommune-projektet var således også at projektet havde været med til at igangsætte en række gennemgående udviklingsprocesser på naturfagsområdet som i hvert fald delvist måtte tilskrives Science-kommune-projektet (ibid.). Det interessante spørgsmål er nu **hvilke af disse udviklingsprocesser der kan forventes at føre til blivende resultater i Science-kommunerne**. Derfor vil vi i det følgende udfolde erfaringerne fra Science-kommune-projektet med særligt fokus på fem cases som illustrative eksempler på nogle af de væsentligste resultater opnået i kommunerne ud

fra et langsigtet perspektiv. Vi vil med dette som baggrund argumentere for at der er mindst to vigtige erfaringer der synes at gøre en Science-kommune befordrende for udvikling på naturfagsområdet, og som derfor er værd at tage ved lære af og holde fast i.

## 2. Om undersøgelsen

I løbet af den treårige projektperiode blev udviklingen i Science-kommunerne fulgt af forskere fra Københavns Universitet med henblik på evaluering af indsatsen (for yderligere metodebeskrivelse se Sølberg & Jensen (2011, s. 2-3 + 43-44)). Nogle af de data som blev indsamlet i den forbindelse, bliver her genfortolket med fokus på hvilke gennemgående træk i udviklingsprocesserne i Science-kommunerne der synes at kunne føre til blivende resultater på naturfagsområdet i kommunerne.

De to første år blev der gennemført årlige telefoninterviews af en times varighed med en naturfagskoordinator fra hver af Science-kommunerne. Spørgeguiden var delt op i temaer baseret på projektmålene, men temaerne udviklede sig fra år til år i forhold til de vigtige aspekter af udviklingsprocessen som naturfagskoordinatorerne gjorde opmærksom på. Naturfagskoordinatorerne blev ledt gennem de forskellige tematikker af interviewerens som sørgede for at udfylde spørgeskemaet for respondenterne undervejs på baggrund af samtalen. Respondenterne blev fx bedt om at vurdere hvor langt deres kommune var som Science-kommune ift. at have samlet en naturfagsbestyrelse el.lign. På baggrund af deres svar vurderede interviewerens hvor på en 5-punkts Likert-skala respondenterne lå, og markerede det i spørgeskemaet. Intervieweren havde dog også mulighed for at skrive kommentarer til de enkelte spørgsmål så uddybende informationer kunne blive noteret. I den udstrækning der ikke var tid til fyldestgørende at få respondenterens svar med undervejs, blev interviewet gennemlyttet umiddelbart efter for at sikre de vigtigste dele af samtalen.

Ud fra analysen af de to første års udvikling fremgik det at der var en række elementer som syntes at pege på særlige udviklingspotentialer på tværs af kommunerne. Disse elementer blev udvalgt til nærmere undersøgelse hvilket dannede baggrunden for tredje års undersøgelse som udgjordes af i alt ni casestudier (hvoraf fem præsenteres her). De eksemplariske cases demonstrerede nogle af de vigtigste resultater opnået i løbet af Science-kommune-projektet. Dermed ikke sagt at den positive udvikling i den enkelte kommune (som var genstand for det givne casestudie) kan tilskrives Science-kommune-projektet alene, men de ni cases var udvalgt netop fordi de repræsenterede dele af det udviklingspotentiale der lå i at forsøge at samle indsatsen omkring naturfagene i en Science-kommune-tænkning. Dataindsamlingen til casestudierne blev indsamlet gennem telefoninterviews som tidligere, men interviewene blev skåret ned til ca. en halv times varighed da interviewene nu kun fokuserede på emnet for

den enkelte case og ikke også skulle dække de andre projektmål som det var tilfældet de første to år. Til gengæld involverede hver case to interviews med hhv. naturfagskoordinatoren fra den givne kommune og endnu en kilde udpeget af interviewer og naturfagskoordinatoren i samråd. Dette blev gjort for at nuancere billedet af forløbet i den enkelte kommune, for at få supplerende oplysninger og i nogle tilfælde for at verificere dele af naturfagskoordinatorens fortælling. En tredje datakilde til interviewene var et totimers interview med Science-kommune-projektlederen som kunne give et supplerende perspektiv på de ni cases. I tabel 1 ses en oversigt over antallet og formålet med de i alt 67 interviews foretaget i den treårige projektperiode.

**Tabel 1.** *Oversigt over antal og formål for de gennemførte interviews med aktører fra Science-kommunerne fra 2009 til 2011.*

	Hovedformål	Antal respondenter
2009	Undersøgelse af kommunernes forudgående forudsætninger for at være en Science-kommune og deres historik omkring arbejde med naturfag.	22
2010	Undersøgelse af hvilke muligheder og barrierer for udvikling der opleves i Science-kommunerne, og hvor langt de er kommet med at etablere sig som Science-kommune.	24
2011	På baggrund af de to forudgående undersøgelser at udvælge elementer som synes at have særlig betydning for udviklingen i Science-kommunerne, til beskrivelse af ni cases.	21

### 3. Hvad skete der under Science-kommune-projektet?

#### 3.1. Den samlede udvikling i Science-kommunerne

I 2009 vurderede 8 ud af 20 naturfagskoordinatorer at de ca. et år inde i projektet stadig kun havde opnået lidt udvikling i forhold til at blive en fungerende Science-kommune. Mod slutningen af projektet vurderede kun 2 kommuner ved selvrapportering på det sidste nationale netværksmøde for naturfagskoordinatorerne at de fortsat kæmpede med at komme i gang med udviklingen. Tilsvarende var der i 2009 kun 3 koordinatorer ud af 20 som vurderede at de var veletablerede Science-kommuner, mens andelen ved projektets afslutning i 2011 var 8 ud af de 20 kommuner. Også på mere konkrete spørgsmål om udviklingen i kommunen var der hen over projektperioden gennemgående tegn på større og flere naturfagsaktiviteter samt mobilisering af flere ressourcer til

naturfagsområdet. Dette kom bl.a. til udtryk da naturfagskoordinatorerne i 2010 blev bedt om at angive tegn på at kommunerne var begyndt at udvikle sig i en produktiv retning. Følgende er udvalgte eksempler på tegn på kulturforandringer beskrevet af naturfagskoordinatorerne (Sølberg, 2010). Med kulturforandringer menes i denne sammenhæng forandringer i en socialt skabt virkelighed, her forstået som *“changes in norms, values, beliefs, expectations and conventional actions of a group”* (Phelan, Davidson & Cao, 1991):

“Der er sket et skred politisk fra satsning på oplevelsesøkonomi over til at ville satse på naturvidenskab i kommunen”

“Der var kampvalg om at komme med i naturfagsbestyrelsen på trods af, at der ikke er penge i det.” “Hver gang der er møde, så dukker borgermesteren, skoledirektøren, skolechefen og den pædagogiske konsulent op.”

“Når vi slår en naturfagslærerstilling op, så er der 60-80 ansøgere”

“Science-kommuneideen er blevet en del af tænkningen, som gennemsyrrer hele arbejdet i kommunen.

“Politikerne ser relevansen og nytten af ideen. Derved er projektet blevet forankret bredt i kommunen (bl.a. i de andre forvaltninger).”

“Man har arbejdet meget på at udvikle lokale naturfaglige kulturer på de enkelte skoler, hvilket indebærer, at lærerne skal arbejde mere fokuseret og bevidst med at udvikle naturfagene. Det er faktisk ikke muligt at være ret kontrær her. Både skolechefen og udviklingschefen er meget rundt på skolerne for at hjælpe dem fremad.”

“Lærernetværket er frivilligt og de får ikke timer til det netværk, men lærerne melder sig alligevel til forskellige aktiviteter”

“Der er masser af naturfagsbegejstring, masser af projekter, masser af ejerskab”

“Der er en øget opmærksomhed blandt mange aktører omkring naturfag, hvilket fx betød at 500 interesserede kunne samles”

“Der er kommet en fælles opfattelse blandt skolelederne omkring at lave en naturfagsplan på den enkelte skole”

“Naturfagslærerne bliver anerkendt som ressourcepersoner på skolerne”

“Der er elever, som lige pludselig er interesseret i naturfag og i at arbejde projektorienteret. Det gav dem positiv status blandt andre elever; lærerne oplevede at de godt kunne være mere tovholdere”

“Der er sket et stort holdningsskift på skolerne i retning af at arbejde med at opbygge en eksperimenterende lærende kultur”

Disse beskrivelser omkring udviklingen indikerede at Science-kommune-projektet havde haft en positiv betydning for naturfagsområdet, og den tendens fortsatte i 2011. Det skal siges at det ikke var alle kommuner som oplevede positive forandringer, ligesom der var stor forskel på udviklingen i de enkelte kommuner. Ikke desto mindre var der rigeligt med eksempler til at indikere at Science-kommune-projektet havde

sat sig positive spor på naturfagsområdet i mange kommuner, og disse eksempler dannede visse mønstre som blev udgangspunkt for vores casestudier.

### 3.2 Fremtidsudsigter for Science-kommuner

Ved det sidste nationale naturfagskoordinatormøde i foråret 2011 var et af de store spørgsmål hvorvidt den opnåede succes kunne fastholdes efter projektperiodens formelle ophør. I tabel 2 nedenfor ses det hvorledes naturfagskoordinatorerne forholdt sig til dette spørgsmål.

**Tabel 2.** Opgørelse over naturfagskoordinatorernes forventninger til fremtidig udvikling på naturfagsområdet i deres kommune.

I hvilken grad tror du at der vil være en udvikling på naturfagsområdet i din kommune de kommende 3 år efter Science-kommune-projektets afslutning?		
	Respondenter	Procent
I meget høj grad	5	20,0 %
I høj grad	12	48,0 %
I nogen grad	8	32,0 %
I mindre grad	0	0,0 %
Slet ikke	0	0,0 %
Ved ikke	0	0,0 %
I alt	25*	100,0 %

(\* Enkelte kommuner var repræsenteret ved to personer. Derfor er det ikke alle 25 Science-kommuner der er repræsenteret i dette datamateriale, selvom der er 25 respondenter).

Som det ses, så herskede der en ganske imponerende optimisme for fremtidens naturfagssatsning blandt naturfagskoordinatorerne på trods af at Science-kommune-projektet sluttede. Ud fra interviewene med naturfagskoordinatorerne var det klart at en stor del af dem havde opnået en grad af kommunal forankring som gjorde at udviklingen kunne fortsætte. Dette var endnu et tegn på at Science-kommune-projektidéen rummede langsigtede udviklingspotentialer. Blandt de konkrete resultater som naturfagskoordinatorerne vurderede som "vigtige blivende effekter" ved det sidste nationale netværksmøde, var følgende: "Naturambassadører i alle børnehaver", "Overblik over aktiviteter og ressourcer på skolerne", "Kommunal handleplan (5-årig) for naturfag", "Læringsfællesskaber (fagteam) på skolerne ledet af en un-

dervisningsvejleder”, “Naturfag er i fokus/synlige på alle skoler”, “Godt samarbejde mellem folkeskoler og gymnasier bl.a. i forbindelse med naturvidenskabsfestival”, “Et nuværende og blivende fokus fra skolelederne i forhold til science”, “Naturfagscenter med kommunale konsulenter og naturvejledere”, “Naturfagsstrategi der er kommunalt vedtaget”, “Projekter/events inden for naturfag der sigter på udvikling af naturfagskultur”, “Der er endelig skabt politisk bevågenhed omkring vigtigheden af en indsats på scienceområdet. Det giver mulighed for videreudvikling”, “Ændring af undervisningsmetoder inden for naturfag”, “Bedre koordineret undervisningstilbud på tværs af skoler”, “Mere åbenhed omkring diskussioner af de didaktiske ting som kan forbedre fagene”, “At jeg er blevet ansat som sciencekoordinator”].

Ovenstående selvrapporterede “vigtige blivende effekter” peger i retning af at Science-kommune-projektet har været med til at iværksætte en kulturændring i forhold til naturfagsområdet i kommunen. At der investeres ressourcer i uddannelse af naturfaglige ressourcepersoner, at der er etableret nye samarbejder og formuleret fremadrettede handleplaner og strategier, og at der er opnået fokus på naturfagsområdet blandt skoleledere såvel som blandt kommunens politikere, er alle resultater som peger på en opblomstring af naturfaglige kulturer i kommunen. De præsenterede resultater er beskrivelser fra forskellige naturfagskoordinatorer og var således ikke nærværende i *alle* Science-kommuner, men de var tilstrækkelig gennemgående til at tegne et overordnet billede af kulturforandringer i størstedelen af kommunerne.

Som det har været vist tidligere, er kulturforandring forudsætning for langsigtet udvikling af praksis (Evans, 1996). Derved er der også grundlag for at sige at de opnåede resultater peger på udviklingsprocesser som er mere dybdegående og derved også mere langsigtede, og at Science-kommune-projektet derfor har været medvirkende til at skabe resultater som har potentiale til at få betydning også ud over projektperioden. Men hvilke elementer i Science-kommune-projektet har særligt bidraget til dette?

### *3.3 Eksemplariske udviklingspotentialer i Science-kommune-projektet*

Der blev i forbindelse med den tredje og sidste evaluering af projektet identificeret ni elementer som havde vist sig at være vigtige for den positive udvikling i nogle af kommunerne (for uddybende casebeskrivelser af alle ni elementer se Sølberg & Jensen (2011)). Af de ni elementer blev især fem fremhævet gennem interviewene med naturfagskoordinatorerne som vigtige for at Science-kommunerne havde opnået blivende resultater på naturfagsområdet. De fem elementer beskriver nogle af de grundlæggende betingelser der tilsyneladende er vigtige hvis man vil opnå langsigtet udvikling på naturfagsområdet gennem en kommunal indsats. Dette vender vi tilbage til efter en kort casebaseret gennemgang af de fem udvalgte elementer.

### 3.3.1 Naturfagskoordinatorerne

Et centralt element i Science-kommune-projektet var at der i hver kommune skulle udpeges (mindst) en kommunal naturfagskoordinator som fik ansvaret for at initiere og koordinere den kommunale indsats. Erfaringerne fra pilotprojektet Science Team K havde vist at det havde afgørende betydning for udviklingsprocessen at der var en lokalt forankret koordinator til at iscenesætte aktiviteter og udbrede indsatsen.

Som udgangspunkt skulle naturfagskoordinatorerne i Science-kommunerne ud over at have en tæt kontakt til skolerne og andre uddannelsesinstitutioner helst også have en vis tilknytning til forvaltningen for at være centralt placeret. Naturfagskoordinatorernes ansættelsesforhold var dog meget forskellige fra kommune til kommune, selvom det oftest var en eksisterende kommunal konsulent som udfyldte rollen. Dette var eksempelvis tilfældet i Tårnby Kommune. Her var naturfagskoordinatoren til at starte med alene om arbejdet. Hun var ansat på deltid som kommunal konsulent på kommunens Pædagogiske Udviklingscenter samtidig med at hun underviste på en af kommunens skoler. Efter aftale med forvaltningen nedsatte hun en arbejdsgruppe til at hjælpe til i løsningen af de mange opgaver som naturfagskoordinatorrollen indebærer. Arbejdsgruppen bestod af ledende repræsentanter fra ungdomsuddannelserne, forvaltninger, naturskoler, skole m.m. Arbejdsgruppen og rutiniseringen af nogle af de tilbagevendende begivenheder i kommunen gav efterhånden naturfagskoordinatoren mulighed for også at tage sig af mere overordnede strategiske opgaver. Mod slutningen af projektperioden blev der udpeget endnu en koordinator med baggrund i matematik til at komplementere og hjælpe med at udfyldte naturfagskoordinatorrollen, hvilket var med til at sikre bæredygtigheden i koordineringen i kommunen og udvide kontaktfladerne i kommunen.

Naturfagskoordinatorerne havde således kontakt til et bredt udsnit af aktørerne på naturfagsområdet i kommunen. De havde eksempelvis kontakt til skolerne dels gennem lærerne i arbejdsgruppen, dels gennem faglige lærernetværk med repræsentanter fra hver skole og gennem en direkte kontakt til skolelederkredsen som de kunne kontakte når omfattende projekter skulle opstartes. I kraft af kontakten til skolerne var det derfor muligt at prioritere indsatserne med udgangspunkt i de eksisterende ressourcer på skolerne, hvilket skabte gode vilkår for blivende forandringer (Bolam et al., 2005). Naturfagskoordinatorerne havde desuden kontakt til både private og offentlige institutioner såvel som vigtige politiske grupper såsom Børne- og Skoleudvalget gennem arbejdsgruppen og deres bagland i forvaltningen. Samlet set fungerede naturfagskoordinatorerne og de personer som omgav dem, som et mellemled mellem praksislaget (både de formelle og de uformelle læringsmiljøer) og det politiske/administrative lag i kommunen. Det målrettede arbejde på tværs af grupperne i kommunen var med til at sikre vedtagelsen af en overordnet handlingsplan for naturfagsområdet i kommunen. Naturfagskoordinatorerne og deres nærmeste

samarbejdspartnere var således afgørende for at sikre en samlet indsats på tværs af grupper i forskellige dele af kommunen.

### 3.3.2 Naturfagsbestyrelsen

Science-kommune-projektet lagde op til at hver kommune etablerede en naturfagsbestyrelse som skulle fungere som en overordnet gruppe af beslutningsdygtige aktører på naturfagsområdet. Naturfagsbestyrelserne skulle hjælpe og inspirere naturfagskoordinatorerne i de forskellige kommuner. Der var meget stor forskel på sammensætningen af naturfagsbestyrelserne, og deres betydning var også meget forskellig afhængigt af sammensætningen og de funktioner som de fik. Nogle af de mest effektive naturfagsbestyrelser var dem som var bredt sammensat med repræsentanter fra både grundskoler og gymnasier, fra forvaltningsregi, fra erhvervslivet samt fra det politiske niveau m.fl. Dette var folk som ikke før Science-kommune-projektet havde anledning til at samles om deres fælles interesse for udvikling på naturfagsområdet.

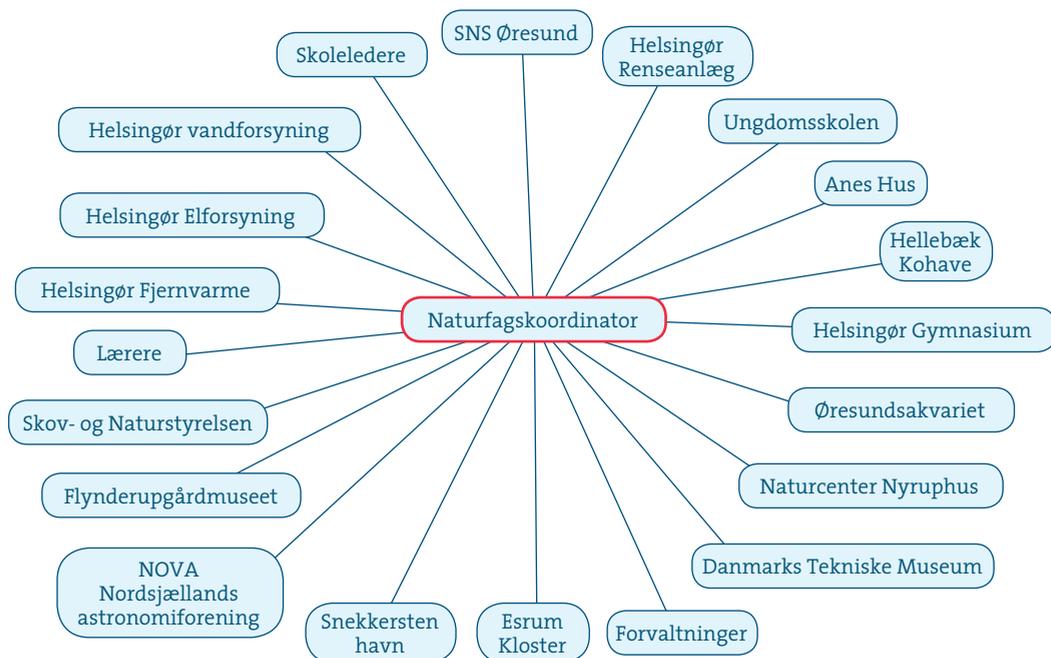
Rudersdal var en af de Science-kommuner hvor man bevidst havde søgt at involvere en bred gruppe af mennesker i den kommunale naturfagsindsats. I stedet for en naturfagsbestyrelse havde man valgt at arbejde med en styregruppe i stedet. Styregruppen bestod oprindeligt af to skolebestyrelsesmedlemmer, en skoleleder, skolechefen, en medarbejder fra forskerparken Scion DTU, chefen for uddannelse og studerende på DTU, repræsentanter fra kommunens to gymnasier, en repræsentant fra en udviklingsvirksomhed og naturfagskoordinatoren. Styregruppen var således meget ressourcestærk og repræsenterede en bred vifte af interessegrupper, hvilket fik stor betydning for den effekt Science-kommune-projektet havde.

Et af de vigtige resultater som må tilskrives styregruppens arbejde, kom af at det lykkedes at få et møde med kommunalbestyrelsen hvor de præsenterede deres vision om en kommunal indsats på naturfagsområdet som ikke kun var knyttet til uddannelsessektoren. Gruppen fik kommunalbestyrelsens opbakning til at gå videre til de enkelte forvaltninger for at inddrage disse i indsatsen. Dette resulterede bl.a. i at Forvaltningen for Teknik og Miljø blev involveret i udviklingen, hvilket ikke alene åbnede for nye undervisningsmuligheder, men også gjorde indsatsen markant mere udbredt. Styregruppen fik således løftet naturfagsindsatsen til en mere gennemgribende og koordineret indsats i kommunen.

### 3.3.3 Netværksdannelse

En vigtig opgave for naturfagskoordinatorerne i overensstemmelse med Science-kommune-projektets formål var at opbygge et overblik over initiativerne på naturfagsområdet. Dette skulle sikre en bedre koordinering af tiltagene og en bedre udnyttelse af ressourcerne i kommunen. Et godt eksempel på hvordan dette kunne opnås, kunne man finde i Helsingør. Her deltog naturfagskoordinatoren i lærernetværksmøder,

fagudvalgsmøder og skoleledermøder og afholdt vejlederuddannelse for lærere og var på den måde tæt på skolerne. Derudover havde han forbindelser til kommunale forvaltninger, ungdomsuddannelser, uformelle læringsmiljøer og mange andre ressourcer i og omkring kommunen illustreret i figur 2:



**Figur 2.** Et udsnit af den kontaktflade som bidrog til Helsingørs naturfagskoordinators overblik over naturfagsressourcerne i kommunen.

Det var tidskrævende og omfattende at opbygge det store netværk der skulle til for at have overblik over ressourcerne og tiltagene i kommunen. Til at starte med var det også først og fremmest naturfagskoordinatoren selv som havde gavn af den store kontaktflade. Men gennem opbygningen af kontakter til de mange forskellige grupper og institutioner blev han opmærksom på de muligheder og eksisterende ressourcer som kommunen rummede, og kunne sætte nye initiativer i gang på den baggrund. Overblikket over kommunens aktører på naturfagsområdet gjorde det også muligt for naturfagskoordinatoren at sætte forskellige aktører i forbindelse med hinanden. Fx fortalte en lærer som havde arbejdet en del sammen med naturfagskoordinatoren, om at hun gennem naturfagskoordinatoren var kommet i kontakt med flere gymnasielærere som hun var begyndt at arbejde sammen med. Hun sagde selv at det

ikke tidligere ville have været noget, hun ville have været tilbøjelig til, men at hun nu havde fået mod på og lyst til at indgå i projekter sammen med ungdomsuddannelser. Ifølge naturfagskoordinatoren var der flere og flere som kontaktede hinanden på tværs af netværket – også uden om naturfagskoordinatoren. Således var en af de vigtigste konsekvenser af naturfagskoordinatorens netværk at der opstod nye relationer mellem aktører i kommunen – vel at mærke ikke kun episodiske relationer, men også mere meningsfulde og varige relationer som er afgørende for at opnå en sammenhængende udvikling (Fullan, 2001).

Naturfagskoordinatorene havde også gennem sine netværk gode muligheder for at indsamle og videreformidle informationer om relevante undervisningstilbud, projekter og andre initiativer til lærere og andre relevante aktører. *“Det er rart at have én der ligesom har det store overblik når man selv sidder og drukner i sit eget lille projekt,”* som en lærer sagde. Læreren fortalte også at hun i modsætning til tidligere nu blev informeret om undervisningstilbud i god tid og ikke først når det var for sent. Derved begyndte flere at benytte ressourcerne i kommunen i højere grad.

### 3.3.4 Politisk forankring

I Vejle Kommune blev koordineringen af Science-kommune-projektet placeret på Videns- og Oplevelsescenteret Økolariet, hvilket vil sige at det ikke var direkte forankret i forvaltningen. Naturfagskoordinatorfunktionen blev delt mellem en ansat i skoletjenesten på Økolariet og en pædagogisk konsulent fra skoleafdelingen. Allerede det første projektår udviklede man en sciencestrategi, men den vandt ikke genklang i det politiske lag i kommunen. Dette ændrede sig drastisk efter at den nyansatte politiske udvalgsformand valgte at kaste sin opmærksomhed på naturfagsområdet. Der opstod på samme tidspunkt en politisk dagsorden omkring udvikling af Region Syddanmark til Science-region, og dette, erfarede naturfagskoordinatorene, var et godt argument for opprioritering af naturfagsindsatsen i Vejle som Science-kommune.

I Vejle blev naturfagsområdet en del af skolernes kvalitetsrapportering i 2009, og naturfagskoordinatorene hyrede et firma til at gøre rapportens indhold overskueligt og tydeligt for politikerne. I rapporten sammenlignedes bl.a. karaktergennemsnit for afgangsprøverne i hhv. Vejle Kommune og på landsplan i både rå tal og let overskuelige søjlediagrammer. Rapporten blev fremlagt for de politiske ledere, og selvom den grundlæggende situation i kommunen ikke havde ændret sig væsentligt fra tidligere år, så gjorde rapporten behovet for en skærpet indsats på naturfagsområdet tydeligt for politikerne. Politikerne valgte derfor at handle på resultaterne i kvalitetsrapporten, og dette forplantede sig til de øverste chefer i forvaltningen. Skolelederne oplevede denne holdningsændring ved at naturfagsområdet blev sat på dagsordenen bl.a. i kompetenceudviklingsstrategien og i skolelederkredsen. På et af skoleledermøderne blev der afsat hele fem timer udelukkende til behandling af naturfagsom-

rådet. Den udbredte politiske bevågenhed blev således afgørende for prioritering af indsatserne på området hele vejen ned gennem systemet, og hermed blev der skabt et stærkt incitament for bl.a. skolelederne til at prioritere naturfagsudviklingen og arbejde mod et fælles mål. Det nye fokus kom til udtryk i en række forskellige tegn på øget opmærksomhed, såsom at en skole ville udvikle naturfagernes prøveformer og gøre dem mere tværfaglige, der var en stigning i søgningen til efteruddannelseskurser som nu skulle foregå i naturfaglige team, og der var i det hele taget en forventning om at "der skulle til at ske noget" selvom rammerne og vilkårene ikke var helt på plads endnu. Så på trods af en decentral organisering af udviklingsmidlerne til skoleområdet lykkedes det gennem den politiske forankring ned gennem systemet at fastholde en fælles indsats.

### 3.3.5 Naturfagsstrategi

Det var et centralt mål med Science-kommune-projektet at hver kommune skulle formulere en naturfagsstrategi som kunne synliggøre naturfagsindsatsen og understøtte udviklingen af den naturfaglige undervisningspraksis. Science-kommunerne arbejdede meget forskelligt med deres naturfagsstrategier både hvad angår formål og omfang, men ultimativt også, hvor stor gennemslagskraft, strategierne havde. I de fleste tilfælde blev naturfagsstrategien udarbejdet af naturfagsbestyrelserne i kommunerne (se mere ovenfor), men i Silkeborg valgte man i stedet at søge taskforce-midler fra Undervisningsministeriet til at finansiere konsulentbistand fra Naturvidenskabernes Hus til at hjælpe med udarbejdelsen af en kommunal naturfagsstrategi. Man nedsatte en arbejdsgruppe som skulle formulere strategiens indhold, og den inkluderede blandt andre to skoleledere fra kommunen. Arbejdsgruppen blev nedsat i juni 2009, og først i efteråret 2010 blev strategien politisk godkendt efter at skolechefen havde bragt strategien op på børn og unge-udvalgsmøde.

Skolelederne blev helt afgørende for den betydning naturfagsstrategien kom til at have i praksis, fordi de kunne formidle strategiens indhold videre til skolelederkredsen i kommunen med legitimitet og troværdighed. Fordi strategien blev videreformidlet gennem fagfæller, mødtes den med megen lydhørhed, hvilket ellers generelt kan være en udfordring når tiltag kommer ovenfra (Stoll et al., 2006). Samtidig var det indskrevet i naturfagsstrategien at hver skole skulle udarbejde sin egen lokale naturfagsstrategi, hvilket overlod en stor del af ansvaret til den enkelte skoleleder. Derved blev den lokale naturfagsstrategi også udformet ud fra forudsætningerne på den enkelte skole, hvilket medvirkede til en reel differentiering af indsatsen på den enkelte skole i overensstemmelse med deres behov og kapacitet (Stoll, 2009). Implementeringen af strategien på de enkelte skoler blev desuden faciliteret af skolekonsulenter og naturvejledere fra AQUA, og dette var med til at sikre at den kommunale strategi ikke blot forblev et politisk dokument, men at ord blev til handling. Denne tilgang har tidligere vist sig

særdeles vigtig for en endelig institutionalisering af nye fokusområder på skoler som har meget forskellige forudsætninger for udvikling (Harris, 2001).

At den kommunale naturfagsstrategi fik så stor betydning på skolerne, kan i høj grad tilskrives at indsatsområderne i strategien var blevet vedtaget på politisk plan, men samtidig at man gjorde en aktiv indsats for at omsætte den til praksis på skolerne. Man havde tidligere forsøgt at sætte fokus på naturfagene inspireret af naturfagsprojektet Science Team K, men det var først i forbindelse med Science-kommune-projektet at det blev muligt at mobilisere de nødvendige ressourcer til at få politisk opbakning til en udformning af en gennemgribende naturfagsstrategi. Naturfagsstrategien fik betydning for udviklingen af naturfagsområdet i praksis fordi arbejdet med de lokale strategier på skolerne var blevet et krav samtidig med at skolerne selv fik indflydelse på den lokale implementering.

#### 4. Hvad kan vi lære af Science-kommune-projektet?

De fem cases præsenteret her er eksempler på resultater og faktorer som var med til at gøre det sandsynligt at udviklingen på naturfagsområdet vil kunne fortsætte de kommende år i nogle af Science-kommunerne. Casene peger alle på markante forandringer i kulturen i kommunerne i en positiv retning – forandringer som synes at være mere eller mindre direkte resultater af processer som Science-kommune-projektet var med til at sætte i gang. De forudgående cases er eksemplariske beskrivelser af udviklingsprocesser som fandt sted – ikke kun i de her repræsenterede kommuner, men også i et vist omfang i flere andre Science-kommuner. Derved er casene både faktuelle, detaljerede og eksemplariske, men samtidig udvalgt med henblik på fremhævelse af en vis generalisering i forhold til vigtige udviklingsprocesser i Science-kommune-projektet.

Ud af casene kan der udledes to overordnede budskaber:

- Enhver større indsats i en kommune skal forankres politisk hvis den skal trænge igennem og afsætte blivende resultater.
- Der er væsentlige fordele ved at etablere et koordinerende netværk af personer med forskellige kompetencer fra forskellige lag i kommunen hvis man skal udnytte ressourcerne på naturfagsområdet i kommunen til at opnå udbredte og bæredygtige resultater.

En uddybende forklaring på disse to budskaber følger her.

##### 4.1. Udbredt politisk forankring

De beslutninger der tages på politisk niveau, har direkte eller indirekte konsekvenser for enhver udviklingsproces i kommunen. I Science-kommune-projektet var sikring

af en politisk opbakning og engagement en vigtig målsætning. Med til det politiske niveau tænker vi bl.a. på kommunale politikere, forvaltningsledere og administrative ledere på uddannelsessteder i kommunen. Med andre ord de mennesker (eller grupper af mennesker) som har direkte indflydelse på rammebetingelserne for en given indsats uanset om det er på forvaltningsniveauet eller på den enkelte skole. Politisk forankring afspejler i denne sammenhæng altså en (mere eller mindre) fælles idé og hensigt med prioriteringen af ressourcerne i kommunen blandt de mest indflydelsesrige aktører på flere niveauer.

I de fleste kommuner var fokuset i projektet på udvikling af naturfagene i folkeskolen. Her spillede skoleledernes engagement en afgørende rolle, bl.a. fordi midlerne til skoleområdet i de fleste kommuner var decentraliserede. Det betød at det var vanskeligt at sætte samlet fokus på et bestemt område uden skoleledernes samtykke. I Vejle førte den opnåede politiske bevågenhed til opbakning blandt skolelederne, og skoleledernes opbakning har afgørende betydning for udviklingen på den enkelte skole i og med at skolelederne i høj grad sætter rammerne for lærernes arbejdsvilkår (McLaughlin & Talbert, 2001, s. 98, citeret i Bolam et al., 2005). Således skal skolelederne medtænkes i den politiske forankring. Tilsvarende var den politiske vedtagelse af en kommunal naturfagsstrategi i Silkeborg et vigtigt skridt da naturfagsstrategien legitimerede indsatsen for såvel skoleledere som lærere. Men samtidig lå der i naturfagsstrategien et vigtigt hensyn til de lokale forudsætninger på den enkelte skole i og med at alle skolerne selv skulle udforme en lokal handlingsplan på naturfagsområdet. På den måde var naturfagsstrategien vigtig for den politiske forankring helt ude på den enkelte skole. I Tårnby var især naturfagskoordinatorerne vigtige for at få sat naturfagsområdet på den politiske dagsorden. De virkede som et forbindelsesled så naturfagsudviklingen på skoleniveau blev koblet til det administrative og politiske niveau i kommunen. På den måde var der i Tårnby en del lighed med Silkeborg. I flere kommuner valgte man at betragte Science-kommune-projektet som et vigtigt led i den overordnede udvikling i kommunen og ikke kun som et naturfagsprojekt, hvilket casen i Rudersdal viste. Styregruppen fik sat gang i et politisk engagement som var med til at forankre udviklingen i kommunen som helhed, og dette kunne lade sig gøre fordi gruppen besad de nødvendige kompetencer til at begå sig i det politiske forum og havde gennemslagskraft nok til at overbevise kommunalbestyrelsen om at støtte op om indsatsen.

#### *4.2 Det kommunale koordinerende netværk*

Når vi i denne sammenhæng omtaler "det kommunale koordinerende netværk", mener vi et netværk som udgøres af de mange forskellige aktører i den enkelte kommune der er forbundet i deres arbejde for udvikling af naturfagsområdet. Her har vi især kigget på OECD's definition af netværk der er som følger:

“Networks are purposefully led entities that are characterized by a commitment to quality, rigour and a focus on outcomes ... They promote the dissemination of good practice, enhance the professional development of teachers, support capacity building schools, mediate between centralized and decentralized structures, and assist in the process of re-structuring and re-culturing educational organizational systems.” (Citeret i Jackson & Temperley, 2007, s. 53, og Hopkins & Jackson, 2003, s. 10)

Ud fra denne definition kan det koordinerende netværk i kommunen ses som det der er med til at bringe de overordnede organisatoriske niveauer i kommunen (fx kommunalbestyrelsen og forvaltninger) sammen med de decentrale enheder hvor man finder forskellige former for naturfaglig praksis – formelle såvel som uformelle (fx skoler, naturskoler, sciencecentre). I denne sammenhæng er naturfagskoordinatoren og naturfagsbestyrelsen vigtige brikker i puslespillet.

Som det fremgår af OECD's netværksdefinition, så er det vigtigt at netværket fungerer som et formålsrettet foretagende, hvilket Science-kommune-projektet har været rammen for.

Vi så i Rudersdal at opbakning fra kommunalpolitisk hold kunne bane vejen for at styrke det kommunale netværk ved at initiere samarbejde på tværs af forvaltninger med et fælles formål – styrkelse af naturfagsundervisningen. Repræsentanter fra styregruppen arbejdede fokuseret på at inkludere flere aktører i det kommunale netværk. En sådan koordination på tværs af forvaltninger eller andre grupperinger kræver forandring af både arbejdsgange, procedurer og tankegange, og i sidste ende bunder mulighederne for forandringer i forandringsevilligheden hos de enkelte aktører (Hall & Hord, 2001). Det er ikke nogen lille opgave, men forandringsevilligheden afhænger af at de enkelte aktører sættes i forbindelse med hinanden så nye relationer kan opstå, hvilket var et af de tydelige resultater fremhævet i eksemplet fra Helsingør. Det omfattende netværk i Helsingør gjorde det muligt for aktørerne i netværket at mødes og opdage hinandens kompetencer således at der kunne opstå gensidigt befrugtende relationer (Fullan, 2001). Som i Tårnby kan naturfagskoordinatoren udfylde en særlig funktion i det kommunale netværk fordi koordinatoren i kraft af sin centrale placering, med tæt kontakt til både skolerne og forvaltningen og herigennem politikerne, kan mægle mellem det koordinerende lag og det praksisnære.

## 5. Afslutning

Science-kommunerne befandt sig ved projektets afslutning på meget forskellige udviklingsstadier. Trods dette har idéen om en kommunal satsning på naturfagsområdet vist et stort potentiale for udvikling og bedre udnyttelse af naturfagsressourcerne i kommunerne. Helt afgørende for udfoldelse af potentialet er at det sker i et samspil

mellem det politiske liv i kommunen og praksisniveauet. For at sikre de bedste rammer for udvikling har der været et udpræget behov for politisk forankring af Science-kommune-indsatsen. Mindst lige så vigtigt har det været at opbygge et veludviklet koordinerende netværk blandt de mange relevante aktører i kommunen. At få alle de forskellige aktører bragt sammen har krævet tid og tålmodighed. Derfor har man efter den treårige projektperiode endnu ikke set det fulde potentiale i Science-kommune-projektet udfolde sig. Mange af de resultater som fremhæves her, er kun indikationer på varig udvikling, og vi kan på nuværende tidspunkt ikke sige hvordan det vil gå med Science-kommunerne. Men projektet har ikke desto mindre vist os hvordan politisk forankring og opbyggelse af netværk har givet muligheder for at skabe synergi mellem de mange gode kræfter som arbejder for udvikling af naturfagsområdet. Vi opfordrer således andre kommuner som vil satse på naturfagene, til at kigge særligt på disse to aspekter når de starter processen.

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Validation of Networks derived from Snowball Sampling of Municipal Science Education Actors

International Journal of Research and Method in Education

Ane von der Fehr (Corresponding author)

Department of Science Education, University of Copenhagen  
and the National Centre for Science Education

Øster Voldgade 3

1350 Kbh. C

Denmark

Phone: +45 22188770

[ane.von.der.fehr@ind.ku.dk](mailto:ane.von.der.fehr@ind.ku.dk)

Jan Sølberg (Co-author)

Department of Science Education, University of Copenhagen

Øster Voldgade 3

1350 Kbh. C

Denmark

Phone: + 45 21697437

[jans@ind.ku.dk](mailto:jans@ind.ku.dk)

Jesper Bruun (Co-author)

Department of Science Education, University of Copenhagen

Øster Voldgade 3

1350 Kbh. C

Denmark

Phone: +45 35320391

[jbruun@ind.ku.dk](mailto:jbruun@ind.ku.dk)

This work was supported by the Innovations Fund Denmark (Innovationsfonden); the Lundbeck Foundation (LundbeckFonden).

This is an Accepted Manuscript of an article published by Taylor & Francis in International Journal of Research & Method in Education on June 13th. 2016, available online: <http://www.tandfonline.com/10.1080/1743727X.2016.1192117>

## Abstract

Social network analysis (SNA) has been used in many educational studies in the past decade, but what these studies have in common is that the populations in question in most cases are defined and known to the researchers studying the networks. Snowball sampling is an SNA methodology most often used to study hidden populations, e.g. groups of homosexual people, drug users or people with sexually transmitted diseases. By use of a snowball sampling approach, this study mapped municipal social networks of educational actors, who were otherwise hidden to the researchers. Subsequently, the resulting networks were validated through interviews with central respondents and by using prior investigations of the municipalities. Our results confirmed that the majority of the designated respondents recognised the resulting sociograms and their own position in these. It was also found that not all predictions based on existing knowledge of the municipalities aligned with SNA data. However, these discrepancies could be explained by development in the municipalities in the time following previous investigations. This study shows that snowball sampling is an applicable method to use for mapping hidden populations in educational settings, but also that qualitative studies are needed in order to interpret the networks in real-life contexts.

Keywords: Social network analysis, snowball sampling, mixed methods, data validity, Science Municipalities.

Social network analysis (SNA) was initially developed within the field of sociometry, which is a systematic approach used to analyse social relationships (de Nooy, Mrvar, and Batagelj 2005, 3). A social network can be defined as a group of actors who are connected to one another through a set of relationships (Daly 2010; Wasserman and Faust 1994). As described in a recent paper, there are basically three approaches to SNA, namely quantitative, qualitative, and mixed-methods SNA (Baker-Doyle 2015). SNA has been used in many different research fields to study relationships, e.g. in organisational development (e.g. McGrath and Krackhardt 2003; Waldstrøm 2003; Tsai 2002), trading (e.g. Kim and Shin 2002), and networks of individuals with infectious diseases (e.g. Stephenson and Zelen 1989).

SNA began to gain foothold in educational research around one decade ago. Since then, SNA has been used to explore educational networks and educational change in a number of studies (e.g. Hite, Williams, and Baugh 2005; Daly and Finnigan 2010; Pitts and Spillane 2009; Baker-Doyle 2015; Moolenaar, Daly, and Slegers 2010). Daly and Finnigan (2010) studied networks of school leaders and central office administrators and found that there were few links between schools and between schools and the central office. In addition, they found the network structures to be centralized which could be inhibiting for educational change since this network structure might constrain information exchange (Daly and Finnigan 2010). Hite, Williams, and Baugh (2005) examined networks of public school administrators and found multiple different networks embedded in the same population of administrators (Hite, Williams, and Baugh 2005). Pitts and Spillane (2009) used SNA to investigate school leadership and were able to capture informal leadership not visible in the formal organisations (Pitts and Spillane 2009). With a focus on the formal organisation of schools, Moolenaar, Daly, and Slegers explored social network positions of leaders in schools. They found that their positions in work-related advice networks and their connections to teachers affected teachers' willingness to engage in generating new

knowledge and practice (Moolenaar, Daly, and Slegers 2010). Baker-Doyle (2015) focused on teachers' networks and revealed shadow networks (existing networks that were not reported) by using a tri-modal model for social network research (Baker-Doyle 2015). Other studies in educational networks have students as the centre of attention. One example is a longitudinal study investigating development of student networks over time (Bruun and Bearden 2014). This study showed that student networks seem to stabilize quickly and that students interact with other students who are immediately available to them through pre-organized sections (ibid).

Turning now to a broader view, importance of the district role in school improvement has been increasingly recognised (Hopkins, Stringfield, Harris, Stoll, and Mackay 2014). Local Education Agencies (LEAs) are examples of actors that can be influential at the district-level, and which have been acknowledged in the context of educational reforms (Spillane and Thompson 1997). Since schools are affected by actors that reach beyond individual schools, it is important not to consider teachers, schools, administrators, LEAs etc. isolated from each other, but to acknowledge how actors from different organisations and levels interact. Methodological designs suited for capturing the complexity of interactions between members of such diverse groups remain few and limited. However, SNA can be a useful tool to this end. Most network studies focus on specific target groups of educational actors. As an example, Penuel, Riel, Krause, and Frank investigated teachers' networks according to distribution of access to resources associated with school reform. As they emphasised, a fuller network analysis considering community members and other school actors would provide a more thorough understanding of the differences in accessible resources (Penuel, Riel, Krause, and Frank 2009). But network studies that include actors from many different parts of the system are limited. The study presented here attempted to capture such transverse networks and validated the method used to describe these networks.

The context of this study was a developmental project involving 25% of all Danish municipalities, called the *Science Municipality Project* (2008-2011) (Jensen and Sølberg 2012). The project aimed to improve the coordination of activities involving science education within the municipality and facilitate new initiatives involving relationships between many different types of actors. A municipal science education coordinator (MSE coordinator) was appointed in each Science Municipality to facilitate coordination of the activities. In Denmark, the municipalities are responsible for primary and lower secondary schools and therefore the municipal setting is important for educational development. This paper presents research conducted in the aftermath of the Science Municipality Project exploring the resulting municipal networks of educational actors in four such Science Municipalities. In the following, these networks will be termed *Municipal Science Education networks* (MSE networks).

The overall purpose of the research conducted in conjunction with the development project was to explore connections between network structures and science education development in MSE networks. In order to pursue this purpose, the first task was to develop a methodological approach necessary to explore the network structures. Findings about connections between network structure and science education development will not be addressed further here. Instead, the purpose of this paper is to explain and validate the snowball sampling approach used to map and explore the network structures as they appeared in designated Science Municipalities. Thus, the current research question is: ***How do networks derived from a snowball sampling approach resonate with qualitative data from network member interviews and previous research?***

First, the design and procedures of the SNA study and the validation process will be explained. The methodological findings on the validation study will be presented and finally

points of attention using a snowball sampling approach in educational research will be discussed.

## **SNA Study Design**

### ***Snowball Sampling Approach***

Before presenting the municipalities designated as research objects, the type of SNA data collection procedure used in the study will be explained. Snowball sampling (also called *chain-referral* or *link-tracing*) is a respondent-driven sampling method used in SNA studies to reach unknown members of more opaque or hidden populations (e.g. drug users and terrorists). The researcher uses initial respondents to find other respondents who are included in the target group of the network analysis. This method therefore requires that the researchers have knowledge about ‘insiders’ in the population to be studied, before beginning the data collection procedure (Atkinson and Flint 2001). In this study a snowball sampling approach was applied and was conducted through the following procedures based on Gile and Handcock (2010) and Illenberger and Flötteröd (2012):

- (1) One or a set of respondents (denoted as *seeds*) answered the SNA questionnaire by naming people (denoted as *alters*) they had a certain relationship to. This person or group of people constituted what is called iteration 0 and served as entering point to the network. In the current study the seed in iteration 0 was the MSE coordinator in each of the four municipalities.
- (2) The alters, who were named by the respondent constituting iteration 0, answered the SNA questionnaire and constituted iteration 1.
- (3) The alters who were named by the respondent(s) constituting iteration 1 and who did not belong to iteration 0 or 1, answered the SNA questionnaire and constituted iteration 2.
- (4) The procedure was repeated until the network was exhausted, i.e. until no new alters were named; alternatively until only 1-2 new alters (who did not have affiliation to organisations, not already represented) were named in the latest iteration.

### ***Designating Municipal Networks***

Previous research conducted in the evaluation of the Science Municipality Project explored the Science Municipalities using a more qualitative approach (Sølberg 2009; Sølberg 2010; Sølberg and Jensen 2011; Jensen and Sølberg 2012). This research pointed to the importance of the MSE coordinators and the function they served in the Science Municipalities. However, the full extent of the MSE networks was hidden in the sense that no comprehensive overview of network members existed, because the actors were connected through more or less formal connections across organisations and job functions. To explore such networks, MSE coordinators were chosen to be seeds for the mapping of the municipal networks. In order to be certain of obtaining sufficient data for the analysis, the municipalities chosen for the study, were municipalities in which the previous qualitative research had revealed some existence of a functional social network of science education actors. Another very important reason for choosing Science Municipalities was for validation purposes. Interview data collected during the Science Municipality Project provided useful information when validating the social network analysis. From these data, researchers had knowledge of the extent to which informal learning environments, educational institutions, administrative or political level, and enterprises played a role in the municipalities’ educational development. This information helped identify any absence of important representatives from these categories in the resulting sociograms. By following up the social network analysis with

interviews it also was possible to explore the underlying cause of any discrepancies between the SNA analysis and previous findings about key actors.

Based on this argumentation four Science Municipalities were chosen for closer study of MSE networks. In order to test alignment between the prior knowledge of the networks in the four municipalities and the sociograms resulting from the snowball sampling approach, researchers made predictions about selected basic network characteristics in each of the four municipalities. The municipalities were chosen to ensure diversity in order to get the most interesting basis for social network comparison. The selected municipalities were characterised by different background variables and predictions of network characteristics as is seen in Table 1:

	Mun S	Mun I	Mun L	Mun U
<b>Characteristics based on qualitative data in 2009-2011<sup>1</sup></b>				
Assessment of developmental stage <sup>2</sup>	Initiation	Sustaining	Developing	Sustaining
Assessment of MSE network size	Small	Large	Medium	Medium
Main characteristics	Few development activities, weak political support, high degree of support from teachers	Strong tradition for science education, many active private partners, large MSE network representing many different actors	Weak political support, highly qualified network of teachers, strong industrial interests	Strong network of teachers, strong political support, strong MSE coordinators
Assessment of representation of organisational categories	All categories, except from enterprises; educational institutions as most dominantly represented	All categories; informal learning environments more represented than in other MSE networks	Representation of educational institutions and few enterprises, but not the administrative level or informal learning environments	All categories, except from enterprises
<b>Municipal key figures<sup>3</sup></b>				
Number of inhabitants in 2012 (in 1000)	83	61	49	41
Population density (inhabitants./sq. km) in 2012	392	506	80	622
Socio economic index in 2012 (lower is better)	0,81	1,08	1.09	0,97
Number of primary schools in 2012	21	10	17	8

Table 1: Characteristics of the selected Science Municipalities. <sup>1</sup>Based on data from the Science Municipality Project (Sølberg and Jensen 2011); <sup>2</sup>Developmental stage is seen as relative to the objectives of the Science Municipality Project, and is loosely based on the developmental stages described in Eaker, DuFour, and Burnette (2002). <sup>3</sup>This data was collected from the public databases from Ministry of Economic Affairs and the Interior (As of August, 2015 [www.noegletal.dk](http://www.noegletal.dk)). The year 2012 was selected because SNA data was collected in 2012.

### ***SNA Data Collection***

To collect data from respondents for the SNA study, an online survey using web-based survey software was designed. Each respondent filled in their name, formal position, place of work, and email. In addition, the respondents were asked about their function and organisational affiliation.

The first part of the SNA questionnaire, which is dealt with in this paper, consisted of one question (the name generator question) to identify alters: *'Who within the municipality have you discussed development of science education with at least four times in the past year?'* In order not to let the wording bias the responses towards certain kinds of actors (teachers, leaders, science communicators etc.), no examples of possible alters were given in the presentation of this question (as in Pitts and Spillane 2009). The object of this question was to identify and connect actors (hereafter vertices) to each other in the MSE networks. It was possible for each respondent to name up to 20 alters. This limit was imposed to guide respondents to choose only the most relevant actors, as there might otherwise be a risk of simple namedropping.

Before the data collection, the SNA questionnaire was tested by a group of nine test respondents representing the potential target groups in the study: people from educational institutions, informal learning environments, enterprises as well as from administrative and political level. They were asked in interviews to reflect on the usability of the questionnaire interface and the clarity of the introduction and the name generator question. In addition, the test respondents were asked to estimate the number of people they would name when answering the name generator question and they claimed that they would name less than 20 people. This test was used as a guideline to set the upper limit of possible alters in the context of this study. The boundaries of the sociograms were thus set by the relationships the respondents had to other vertices.

In the name generator question, the potential alters of the respondents were also filtered through a timespan (the past year) and a frequency criterion (at least four times). These criteria served the purpose of limiting the sampling to include only actors who actively contributed to the development of science education within the municipality. Also, the name generator question restricted the sampling to include only actors who worked in the municipality (as geographical region). This was done in spite of the knowledge that people from outside the municipality could potentially have a profound influence on the development of science education within a given municipality. The reason for this additional criterion was that it enabled the focus on the social network within a limited geographical area working under similar municipal regulation and conditions. There were cases in which the municipality affiliation of certain alters was brought into question by the researchers. In these cases, the respondents were contacted in order to confirm the municipal affiliation of the alters they had named in their response. This additional work was done to ensure the validity of the data from the SNA questionnaire. Results showed that only a total of four respondents (distributed in three municipalities) had named alters who were not affiliated to

the municipality. This had led to naming of 12 alters (three, three and six in the three municipalities, respectively) who were deleted by the researcher during the data processing, because they did not meet the criteria set by the name generator question and thereby constituted false-positives.

After analysing data from iteration 0, it seemed that some organisations were not represented as expected based on data from the Science Municipality Project. Therefore, it was decided to give the MSE coordinators, who served as seed vertices, a chance to add further alters to their initial responses, in cases where they conceded that they had not answered exhaustively. This was done to ensure that important parts of the social network were not unduly eliminated in iteration 0. Consequently, six alters in one municipality and two alters in another municipality were added to the response from iteration 0. Theoretically, the added vertices should have been identified anyway as part of the iterative process, but this could have delayed data collection unnecessarily. Thereby, the MSE coordinators were treated slightly differently than the other respondents in order to facilitate the process.

To ensure a high response rate and quality of the data, a number of other precautions were taken before and during data collection. Before the researchers distributed the SNA questionnaires, the MSE coordinators were provided with an info sheet about the survey for further distribution to potential respondents. During the data collection, in cases where respondents did not reply to the initial survey inquiry, up to three email reminders were sent. In addition, in cases where respondents started answering but did not complete the survey, a personal email from a researcher was sent offering help with questions or technical problems. The stringent reminder procedure and personal offers of assistance was time consuming, but this was done in order to optimise response rates and the quality of responses.

### ***Limitations***

The methodological approach builds on inherent assumptions, which we wish to unfold here. In spite of the effort to ensure the quality of data, a number of methodological conditions should be considered in connection to snowball SNA studies and these are also discussed in the following.

#### *Assumptions regarding the Methodological Approach*

Sociograms generated through snowball sampling approximate complete social networks as further iterations of sampling based on seed vertices' responses fail to generate new vertices. In the current study, we assumed that we had reached a reasonable saturation, when only 1-2 alters (who did not have affiliation to organisations not already represented in the sampling) were named in the latest iteration. This assumption was premised on the notion that most members of a social network can be identified even if some members refrain from participating in the investigation. The verity of this assumption depends on the centrality of the seed vertices, the validity and reliability in their responses, and the response rate. Because of this, it is possible that given vertices or whole communities fail to be identified in snowball sampling.

Another issue in the study is the implicit assumption of reciprocity in the network relationships. This originates from the verb 'to discuss' in the name generator question. One might assume that the links in the sociograms would be reciprocated. However, we found that this was not always the case. This could be explained by different interpretations of the name generator question or lack of exhaustive responses by individuals.

### *Selection Bias*

Apart from the seed vertices, the researchers do not have control over which vertices are included in the sample. This means that a sociogram based on a snowball sampling approach is delimited on the basis of the names generated in the initial responses. Therefore, both high response rates and high reliability and validity in the responses, especially from iteration 0, are key in ensuring validity of the data. Since inclusion of vertices is dependent on the names generated by the respondent(s), snowball sampling entails a possible selection bias. The selection bias can be caused by possible misinterpretation of the name generator question, possibility of homophily ('a contact between similar people occurs at a higher rate than among dissimilar people' (McPherson, Smith-Lovin, and Cook 2001, 416)) or overrepresentation of vertices with high degree, because they are more likely to be included in the sample (Illenberger and Flötteröd 2012).

### *False-positive Vertices*

The names generated in snowball sampling is dependent on the respondents' interpretation of the name generator question (Atkinson and Flint 2001). This means that false-positive vertices (alters who are named by respondents, but who do not fulfil criteria for the population in question) might appear in the data set. Therefore, datasets need to be cleaned so that only alters, who fulfil the criteria stated in the name generator question, are included in mapping of the social network.

### *Defining the Limits of the Sampling*

One must consider the cost-benefit of criteria in the name generator question, balancing the possible exclusion of important vertices against the inclusion of vertices of little or no importance according to the population of interest.

### *Memory as a Premise in Data Collection*

Another circumstance to be aware of, when applying a snowball sampling approach, is that the respondents' immediate memories affect the results (Marsden 2011, 374). The names generated are dependent on what names immediately spring to mind, when a respondent is answering the questionnaire. One respondent in the study also pointed this out. This consideration is particularly pertinent in snowball sampling where it is not possible only to use a roster for the name generator question.

### *Respondent Fatigue*

A last aspect which may affect the results is respondent fatigue (Pustejovsky and Spillane 2009). In the questionnaire used in this study only one name generator question existed. But because of formats in the survey program, the respondents were asked the name generator question as many times as the number of alters they mentioned. Such circumstances might give rise to respondent fatigue and calls for survey software that can help the respondents fill out the survey as smoothly as possible.

### *Designating Interview Respondents*

A number of interviews were planned for the qualitative validation study in order to validate the emergent representations of the MSE networks. Sociograms were analysed at the level of

individual vertices in order to designate respondents for interviews. For all vertices in the sociograms a number of centrality measures were calculated. Overall centrality can be assessed as measures of importance inferring social control, even though one should be cautious not to rely uncritically on the connection between centrality and importance (van der Hulst 2011). The centrality measures included in this study were indegree, closeness, and betweenness centrality. In addition to these well described centrality measures, Google PageRank centrality was calculated, alter diversity (according to organisational affiliation) was measured for each vertex and cutpoints (vertices connecting a part of the network to the rest of the network (Hanneman and Riddle 2011)) were analysed. The respondents were selected for interviews following certain criteria: For indegree, the vertices who were named in at least 25 %<sup>1</sup> of the positive responses (responses wherein at least one alter was named) were selected. For the rest of the centrality measures, the three vertices with highest scores were selected. In cases where several vertices had the same score, all vertices with the given score were selected. This selection strategy was chosen because central vertices were needed to validate the results of the SNA study, but at the same time there was a practical limit to the number of respondents who could be included in the study in order to obtain the necessary information.

### ***Interview Design***

Individual interview guides based on a common template were designed to address the validity of the snowball sampling approach. The interview guides were designed to assess whether the sociograms provided a valid estimate of the MSE network structure in each municipality.

The selected central respondents were asked by email to participate in a follow-up interview. In the email it was explained that they had a central position in the network and that they therefore were important for the validation. It was the experience that emphasising their importance contributed to the respondents' willingness to participate. Out of 27 respondents, only three respondents refrained from answering and only two declined to participate in the interview.

Before the interviews, each respondent received another email with a brief outline of the aim of the interview along with an anonymised visual sociogram of the MSE network in their municipality. In the sociogram, all vertices were marked with a number and the colour of the vertices depicted the vertices' organisational affiliation. Figure 1 shows an example of a sociogram sent to the respondents before each interview. An explanation of how to read this sociogram was provided in the email as well. The sociogram was used during the interview as a common basis for validation and discussion of features of the represented social network. This was done to test whether the snowball sampling rendered realistic representations of the MSE networks. We asked respondents to validate important characteristics of the sociograms and thereby attempted to add credibility to the sampling method. In this way, we used a qualitative approach to explore the extent to which the resulting sociograms mirrored the social network in each municipality.

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<sup>1</sup> In the cases where no vertex was named by at least 25 % of the positive responses, the vertex with the highest indegree was selected.

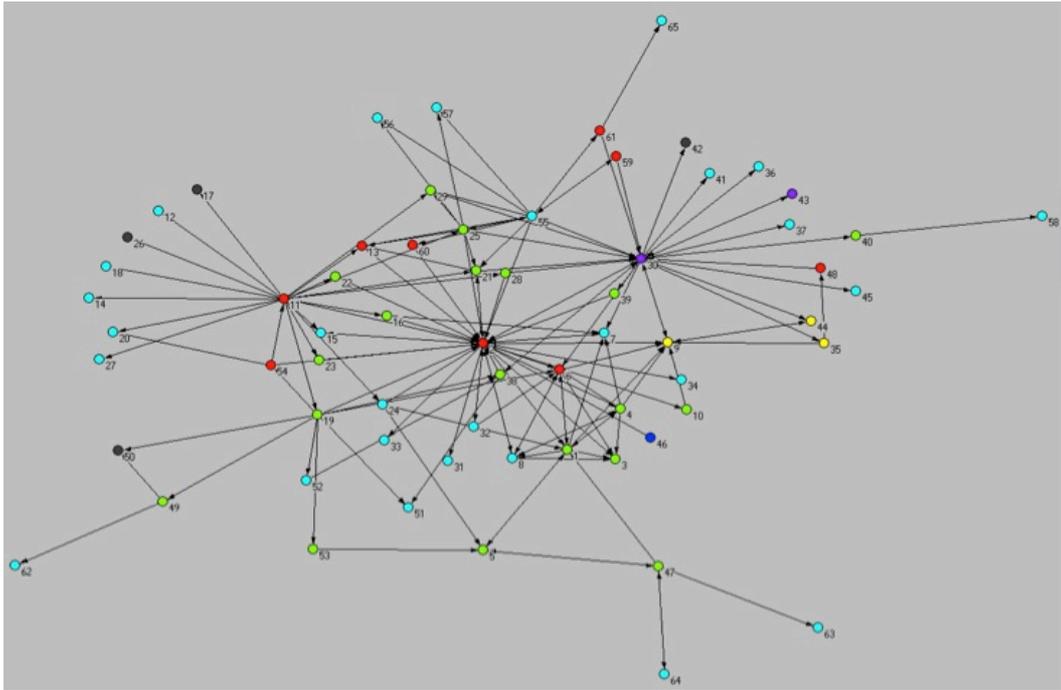


Figure 1: An example of a sociogram sent to the respondents for use in discussions during qualitative interviews in one of the four municipalities. Each node represents an actor and each arrow represents the directional relationship between nodes. The colours depict which organisational affiliation the respondents had declared in the SNA questionnaire.

All interviews were planned as telephone interviews and each lasted from 45-90 minutes. The respondents were asked to provide an informed guess about which vertex represented them in the sociogram. They were also asked to designate the vertex they thought represented the MSE coordinator. In addition, the respondents were asked about whole-network features like the size of the sociogram (number of vertices) and representation of organisational categories (number of vertices affiliated to each of the organisational categories in the sociogram).

### SNA Results

All quantitative social network data sets were represented as sociograms by use of the software Pajek (de Nooy, Mrvar, and Batagelj 2005) (see Figure 1) and the data sets were analysed on whole-network level as well as vertex level. Table 2 shows an overview of the data collected and selected whole-network characteristics. The whole-network measures are detailed in the following.

	Mun S	Mun I	Mun L	Mun U
<b>Results on data collection and basic network characteristics:</b>				
Positive responses	45	28	15	40
Negative responses	3	6	0	4
Response rate	$(45+3)/75 = 64\%$	$(28+6)/55 = 61,8\%$	$15/24 = 62,5\%$	$(40+4)/65 = 67,7\%$
Number of vertices in total (network size)	75	55	24	65
Number of links (relationships)	175	128	54	157
Network density <sup>2</sup>	0.0315	0.0431	0.0978	0.0377
Representation of organisational categories	All	All	All	All

Table 2: Results on data collection and selected whole-network measures calculated for the four MSE networks. Positive responses are responses where at least one alter was named. Negative responses are responses where the respondent declared not to have any alters complying with the name generator question.

The organisational categories in the study included: educational institutions, informal learning environments, enterprises, and administrative and political level. The additional category, 'Other', was included in the questionnaire in case some respondents did not find the four categories comprehensive. An artefact was suspected in the result regarding representation of organisational categories in Mun S since the two respondents who claimed to have affiliation to an informal learning environment worked in schools. A similar artefact was suspected in Mun I since the respondent who claimed to have affiliation to an enterprise had a job function not corresponding to this affiliation.

### ***Basic Network Characteristics***

#### *Network Size*

The number of total vertices gives a measure of the size of the overall MSE network indicating how many people comprised the network. Relationships between data concerning municipality size (geographical area, number of inhabitants and number of basic schools) and the size of the sociogram were tested for possible correlations. The results showed no correlations between municipal size and the size of the sociograms.

#### *Links and Network Density*

The number of possible links has a theoretical upper limit defined by the number of vertices. But the possible number of links also has a practical limit, since the number of relationships a person can administrate is limited. A study of student networks showed a sharp drop-off

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<sup>2</sup> The density is dependent on the number of vertices in the sociogram and in this study, the number of possible links were limited because of the limit on possible alters (i.e. 20 alters). Therefore one can argue that it is appropriate to reflect this in the density calculation: No. of links / (No. of vertices x 20)

around 15 alters (Bruun and Bearden 2014). In our study, the possible number of links was limited by the SNA questionnaire, because the maximum number of alters respondents could name was 20. Not surprisingly, the number of total links was higher in sociograms comprised of many vertices and lower in sociograms with fewer vertices. Network density is defined as the number of actual links divided by the theoretical maximum number of links (Wasserman and Faust 1994, 129). This hypothetical density is presented in Table 2.

### Categorisation of Vertices

In addition to providing information about their job function, the respondents were asked to choose which of following organisational categories best described their work place: ‘*Informal learning environments*’, ‘*Educational institutions*’, ‘*Administrative or political level*’, ‘*Enterprises*’, or the additional category ‘*Other*’. In cases where the respondents had several organisational affiliations, they were asked to choose the category most relevant to their work with developing science education. There were a few instances of discrepancy in the data when respondents’ proclaimed to have a job function that did not coincide with their organisational affiliation – e.g. a school teacher who declared to be affiliated to an informal learning environment instead of an educational institution (as was the case in Mun S). But overall, the respondents did not express difficulties in choosing among the available categories. Figure 2 shows a diagram of the distribution of respondents according to organisational affiliation.

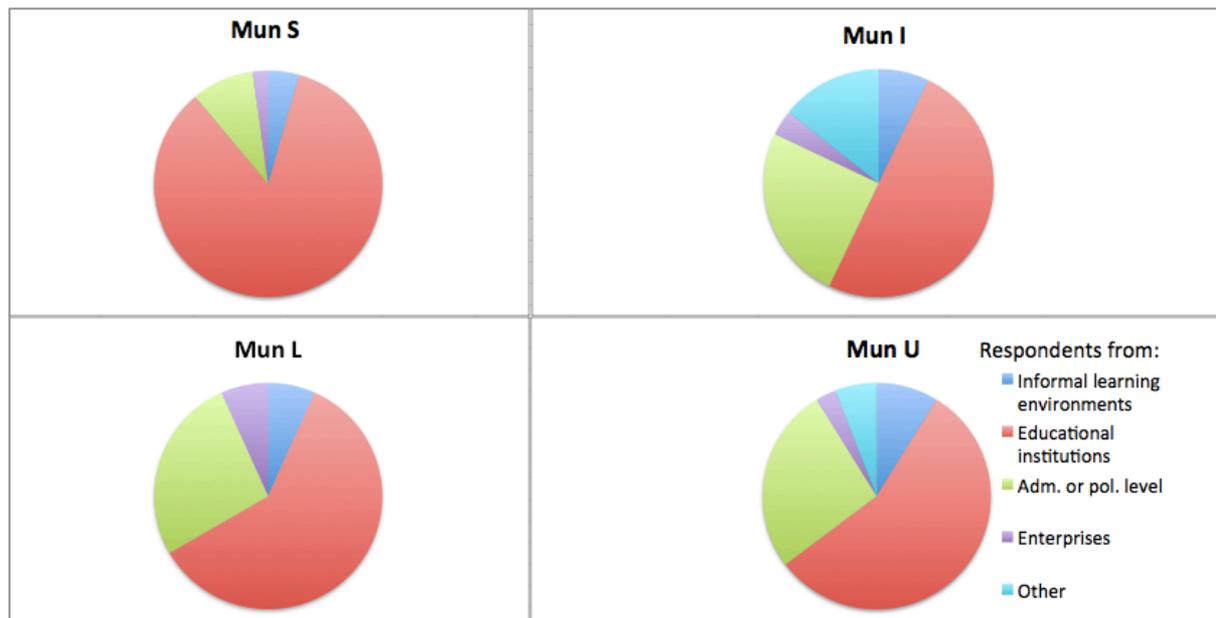


Figure 2: Diagram showing the distribution of the respondents in the five organisational categories in the four municipalities. Only the respondents who ascribed an organisational affiliation in the SNA questionnaire are included in this figure.

As can be seen, the majority of the respondents were affiliated to educational institutions and only a few were from enterprises or informal learning environments. The numbers of representatives from the administrative and political level varied slightly between the municipalities.

**Validation Analysis and Discussion**  
**Results on SNA Data Collection**

Each of the identified actors gave either a positive response by naming at least one alter, a negative response i.e. answering the survey but declaring not to have any alters complying with the name generator question, or no response at all. The number of positive responses correlated with the number of vertices in the sociograms (network size) to some degree, with the highest number of positive responses in the largest sociograms and vice versa. Despite the differences in network size the response rate only varied from 61,8-67,7 %. Taking into account, that none of the respondents were obliged to answer the questionnaire and the fact that the respondent groups in question are targets for many survey inquiries, this response rate can be considered to be very high. The high response rate indicated that the comprehensive measures taken to secure responses worked as intended.

**Analyzing Respondents' Network Perceptions**

All interviews were transcribed and subsequently analysed to identify the following aspects:

- How well were respondents able to identify themselves or a topological equivalent vertex in the anonymised sociograms?
- How well were respondents able to identify the vertex representing the MSE coordinator in the sociogram?
- To what degree were respondents able to recognise the number of vertices in the sociograms and the organisational distribution of vertices?

Table 3 shows the distribution of respondents' recognition of the sociograms.

<b>Respondents' recognition of:</b>	Total number of respondents	Fully recognised	Partially recognised	Not recognised	No answer	No reliable answer
Own position	22	n=11	n=6	n=3	n=2	n=0
MSE coordinator's position	18	n=15	n=0	n=2	n=1	n=0
Network size (number of vertices)	22	n=8	n=4	n=6	n=3	n=1
Distribution of vertices in organisational categories	22	n=12	n=4	n=1	n=2	n=3

Table 3: Respondents' recognition of sociograms of MSE networks in terms of own position, MSE coordinator's position, network size and distribution of vertices in organisational categories.

### *Respondents' Recognition of Own Position*

Half of the 22 respondents were able to recognise which vertex that represented them in the sociogram (Fully recognised). Of the 11 respondents who were able to fully recognise their own position, 10 of them designated the right vertex in their first attempt. To explore the reasoning behind their guesses the researcher asked about the basis on which they made their guess. Six of the respondents designated a vertex with some degree of typological equivalence to their own position (Partially recognised), whereas three were neither able to designate the right vertex, nor a typological equivalent vertex (Not recognised). Two respondents provided no answer. In order to maintain the anonymity of the other vertices, the respondents' guesses were not confirmed or denied by the researcher. The results showed that the majority of the respondents could recognise their own position or an equivalent position in the anonymised sociogram of the MSE network in their municipality. This was in turn interpreted to mean that the sociograms resonated with around half of the respondents' understanding of the social networks.

### *Respondents' Recognition of MSE coordinator's Position*

15 of the 18 respondents were able to recognise the vertex that represented the MSE coordinator (Fully recognised), whereas two designated a wrong vertex (Not recognised). In one case the respondent was not aware that an MSE coordinator was present in the municipality and hence this respondent was not able to provide an answer to this question. When answering this question, the respondents who provided wrong guesses were confused by the MSE coordinator's organisational affiliation depicted in the sociogram. In all four municipalities, the MSE coordinators labelled themselves as affiliated to the administrative or political level, even though some of them had some degree of affiliation to educational institutions as well. This double role of the MSE coordinators made it difficult for some of the respondents to recognise them in the sociograms. Despite of this confusion, the MSE coordinators' position in the MSE networks seemed to be so prominent that the vast majority of the designated respondents were able to recognise them in the sociograms.

### *Respondents' Recognition of Network Size*

Eight of the 22 respondents found the number of vertices in the sociogram of their MSE network to be realistic (Fully recognised). Examples of statements, which were categorized as 'Fully recognised' were: '...that's probably right', '...for that point in time, it is an accurate picture', 'I think that sounds pretty reasonable'. The category 'Fully recognised' were distinguished from the category 'Partially recognised', where the respondents estimated the number of vertices in the sociogram to be close to the actual number. The responses in the category 'Partially recognised' constituted four of the responses and following are examples of statements that placed these answers in-between the category of 'Fully recognised' and 'Not recognised': 'It fits quite well ...there aren't more, but maybe a bit fewer', 'Pretty reasonable, but a bit fewer than 24 in all', 'It fits quite well, there may be a few more people – maybe 60 [instead of 55 as in the sociogram]'. Statements like these made it necessary to add the category 'Partially recognised' in validation of network size. The responses regarded as 'Partially recognised' were distinguished from the responses in the category 'Not recognised' which included examples where the respondents estimated the actual number of actors to be either considerably higher or lower than the number of vertices in the sociogram: '...then it should reach about a hundred...yes, maybe higher than that when we count

everything [in the network of 75 vertices]’, ‘... Around a hundred... [in the network of 65 vertices]’, ‘There are fewer, right [than 24]...I can only recognise those I meet at the [science teacher counsellor] network meetings we have ... we are five-six there.’ When the last respondent was reminded that there were not only teachers in the sociogram she said that it was hard to assess the number, and her final remark was: ‘My experience is that there is not a lot interest in it [i.e. developing science education]’. One factor that may have contributed to relative high number of responses in the category ‘Not recognised’ (six out of 22) was that different respondents could have interpreted the wording of the name generator question slightly differently from each other and therefore they may have assessed the number of actors in the MSE networks differently. Three respondents did not provide an answer either because they stated that they were unable to or because they simply didn’t have an answer. One respondent provided an answer, but because he was not aware who the MSE coordinator was, his answer was deemed to be unreliable because this indicated a lack of knowledge of the MSE network as a whole.

The results show that it was difficult for some of the respondents to recognise network size, but 12 of the respondents estimated the number to be realistic or close to the actual number of actors. This again indicated that the snowball sampling method had revealed sociograms of social networks that were recognisable for central respondents.

#### *Respondents’ Recognition of the Distribution of Vertices in Organisational Categories*

16 of 22 the respondents recognised the distribution of vertices in organisational categories fully or partially. The responses were regarded as ‘Partially recognised’ if the respondents indicated that only one of the four organisational categories were over- or underrepresented. In the one case where the distribution in the sociogram was not recognised, the number of actors affiliated to one category was estimated by the respondent to be double that of the respective number of vertices in the sociogram. The statement was deemed to be too far from the actual results that is was taken to be a sign that the respondent did not recognise the sociogram. Two respondents considered themselves unable to answer the question about the distribution and three answers were deemed unusable because of inconsistencies in the respondents’ answers. As shown, the majority of the respondents were able to recognise the distribution of the organisational categories and thus seemed to validate the social network analysis.

It was evident that even though some respondents found it difficult to answer the validation questions, the vast majority of the respondents answered and confirmed the information in the sociograms for each municipality.

#### *Predictions about the MSE networks*

When we selected the four target municipalities, we made some predictions about the different MSE networks based on prior knowledge about the networks from the evaluation of the Science Municipalities project (Sølberg and Jensen 2011). As it turned out, there were several surprises in the findings from the SNA study. For example, Mun S turned out to have the largest MSE network and Mun I to have the second smallest MSE network, where we had predicted the opposite. One possible explanation for the unexpected results could be that the snowball approach failed to identify parts of the MSE network or had created false-positive vertices. But as more than half of the respondents in the four municipalities recognised the network size fully or partially another explanation could be that the MSE networks had changed since 2011. This explanation was supported by additional interviews with the MSE

coordinators in Mun S and Mun I. In Mun I, the MSE coordinator explained that activities had been slowing down in the year following the Science Municipality Project and that a network study would have included more actors if it had taken place two years before. The opposite was the case in Mun S, where the MSE coordinator explained that a continuous development had taken place since the Science Municipality Project ended and that the effort for science education had increased in terms of both collaboration and new initiatives.

The representation of vertices affiliated to the different organisational categories (Figure 2) reached a considerable degree of alignment with our predictions. As we expected, vertices from educational institutions were dominant in Mun S and enterprises only weakly represented. The informal learning environments were not represented as much as expected in Mun I, but this might be explained if respondents from informal learning environments seemed to identify themselves with the more open category '*Other*'. In Mun L, the proportion of respondents in the category '*Administrative or political level*' was larger than predicted, whereas the informal learning environments were presented to a lesser degree. As expected, enterprises were underrepresented in the municipalities and in Mun U only one vertex chose this category, which was close to the expected. So in spite of these surprises, the resulting data from the SNA study agreed with our overall predictions.

## Discussion

Education is characterised by different kinds of social networks. In some networks, members are defined by a common affiliation and formal relationships (e.g. teachers and leaders of schools) and most SNA studies focus on this kind of social networks. Such networks can be captured through more traditional SNA approaches. Other social networks are composed of members with diverse affiliations and less formal relationships. This was the case with the MSE networks. Members of such networks are not easily identified. In order to investigate these networks, we used snowball sampling. Snowball sampling has previously been used as an attempt to map national networks of stakeholders (including policy makers) in a large EU project focusing on science, technology and math education (Assist Me) (Bruun, Evans, and Dolin 2015). By using snowball sampling in a municipal context, this study adds a new dimension to our understanding of educational networks in this arena. Network data can serve as important information to policy makers regarding effects of educational initiatives on the school level (Penuel et al. 2009). In this way, educational research may be instrumental in guiding decisions regarding future efforts (Coburn, Honig, and Stein 2009).

What makes snowball sampling feasible in educational networks, is that the connecting activity of its constituting members is not shady as in networks of drug users, terrorists etc. The overall aim in educational SNA studies is to improve students' learning and as such does not entail high stake risks for the respondents participating in the study. There seems to be no costs except for the time spend on filling out the survey. It is likely that this increased the willingness of respondents to participate in this study. In addition, the interview respondents could benefit because they were provided with insights into the MSE network in their municipality.

So far, no other methods provide similar possibilities for mapping and exploring MSE networks. In other contexts, technology-assisted approaches to network analysis are being tested. These include collecting email and phone data, or data on physical proximity by use of cell phone devices. Such methods have not been feasible in this study, but innovative use of technologies may open possibilities for future investigations.

## **Conclusion and Implications**

This study found that snowball sampling is an applicable method to reveal and explore the hidden social networks of relevant actors, who constitute important resources in the continuous work developing science education in municipalities. Using a person known to be central in each municipality as the seed, we were able to generate valid sociograms based on SNA. While we are acutely aware of the limitations of this method of sampling, the respondents' recognition of the sociograms indicated the sampling had managed to identify the majority of the actors involved in the MSE networks. In this way, the study has paved the way for others to conduct similar studies of complex educational networks.

In spite of these results, the findings draw attention to the fact that interpretation and understanding of the network data necessitates qualitative approaches as well. Results from the SNA study did not fully align with our prior knowledge about the MSE networks as the networks had changed significantly in the period between the end of the Science Municipality Project and the time when the SNA study was conducted. This demonstrates that social networks consisting of educational actors are not stable entities but dynamic and prone to fluctuating composition and varying size as the conditions for science education in each municipality changes.

## **Acknowledgements**

We owe great thanks to the colleagues at Department of Science Education who have qualified the study. A special thank to all respondents including MSE coordinators in Science Municipalities and lastly a special thank to industrial supervisor Hans Colind Hansen.

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Qualitative Exploration of Centralities in Municipal Science Education Networks

Ane von der Fehr and Jan Sølberg  
University of Copenhagen

Author note

Ane von der Fehr, Astra and Department of Science Education, University of Copenhagen,  
and Jan Sølberg, Department of Science Education, University of Copenhagen.

This research was supported by the Innovations Fund Denmark (Innovationsfonden) and the  
Lundbeck Foundation (LundbeckFonden) awarded to.

Correspondence concerning this article should be addressed to Ane von der Fehr, Department  
of Science Education, University of Copenhagen, Øster Voldgade 3, 1350 Kbh. C, Denmark.  
E-mail: [ane.von.der.fehr@ind.ku.dk](mailto:ane.von.der.fehr@ind.ku.dk)

### Abstract

This article examines mechanisms in educational change through a network analysis study of social networks involving science education actors. Social networks supporting science education development engage diverse actors and in order to understand how these actors may support such development, we explored central actors in four municipal science education networks (MSE networks) using three different measures of centrality. The centrality measures differed in terms of the kind of functions associated with the central position and it was found that the functions focused on mobilisation of resources in the MSE networks. In addition, we found that the central actors comprised a small core of key actors. These results imply that especially a few central actors in MSE networks play pivotal roles in development of science education. The accumulation of centralities on certain actors indicates a degree of vulnerability in the MSE networks.

*Keywords:* centrality, social network analysis, science education development

In recent years, research in school development has shifted focus from individual schools as *Professional Learning Communities* (PLCs) (Stoll & Louis, 2007) towards schools as part of *Networked Learning Communities* (NLCs). NLCs can be described as groups of schools working together to enhance learning and capacity for improvement (Katz & Earl, 2010). The importance of external actors in NLCs, who are not primarily linked to schools, has been emphasised (Jackson & Temperley, 2007) and similarly, this is an acknowledgement of the importance of external actors in PLCs (Hipp, Huffman, Pankake, & Olivier, 2008). In science education, it has been shown to be critically important to consider a variety of actors such as municipal consultants, municipal authorities, policy-makers, and informal teaching and learning environments when investigating science educational development (Sillasen & Valero, 2013). This means that actors involved in development of education within and outside schools form complex social networks and an important step in understanding development of science teaching includes identifying the key actors and the relationships between them that enable them to form social networks. Using Social Network Analysis (SNA) we can identify actors, who hold central positions in the social network and thereby investigate how they contribute to the development of science education.

The context for investigating the social network of actors involved in science education was a developmental project, called the *Science Municipality Project* (2008-2011) (SM project) which involved 25% of all Danish municipalities (Jensen & Sølberg, 2012). Danish municipalities are regional administrative units that are politically led and act as legislative authority for local affairs, including primary and lower secondary schools. The aim of the SM project was to develop municipal support structures (e.g. science education coordinators, science strategies, and science education boards) to improve coordination of activities involving science education and to facilitate new initiatives in order to benefit more from the resources already available in each municipality<sup>1</sup>. Resources can be considered as tangible or intangible (Tsai, 2000). Tangible resources are resources in the physical sense, such as materials, whereas intangible resources are to be considered in a more non-physical sense as for example knowhow.

Results from the SM project indicated that in addition to having the project politically embedded in municipal policies, the successful implementation and sustainability of the project initiatives depended on the interplay between diverse actors involved in science education development within the municipalities (Jensen & Sølberg, 2012). In this study, these actors and the relationships connecting them are considered to be a particular form of social networks hereafter termed *municipal science education networks* (MSE networks). To achieve a more thorough understanding of the MSE networks, a SNA study was conducted to identify key actors and their relative importance in the networks. We wanted to know ***how actors in central positions help mobilise resources in MSE networks?***

### **Social Networks in Science Municipalities**

Social Network Analysis focus on “relationships among social entities” (Wasserman & Faust, 1994, p. 3) and allows for empirical investigation of the relational structures within a social network of diverse groups of actors. SNA has previously been used to study social networks in a variety of educational contexts, e.g. among school administrators on different levels (e.g. Hite, Williams, & Baugh, 2005) and teachers (e.g. Baker-Doyle, 2015). Most often, SNA studies within educational research focus on well-defined groups of educational

<sup>1</sup> <http://danishsciencefactory.dk/science-municipality-project>, accessed Mar. 11th. 2016.

actors, e.g. networks of teachers or networks of school leaders, or networks including few different pre-described groups of actors e.g. school leaders *and* central office administrators (e.g. Daly & Finnigan, 2010), or school leaders *and* teachers (e.g. Pitts & Spillane, 2009). MSE networks in municipal science education are comprised of actors affiliated to many different organisations that exert influence across a range of other actors and organisations at different hierarchical levels within the municipality. In the current study, we explored the social networks of *any* actors involved in science education development in municipalities without restricting the analysis to pre-described groups. The actors spanned different organisations and hierarchical levels within the municipal system and could not be accurately identified in advance because they could potentially be anyone formally or less formally involved in science education within the municipality and therefore hidden to us.

SNA provided a means to identify these otherwise hidden actors and identify their relationships in the social networks, whereby individual actors' relative position in the network could be measured. In social networks, some actors have more central positions based on their relationships with other actors in the network (Freeman, 1979; Scott & Carrington, 2011; Wasserman & Faust, 1994). Using different centrality measures, we were able to find the most significant members within each municipality based on their individual centrality and thereby we were able to examine how their position enabled them to facilitate science education development.

## Method

### Mapping MSE Networks

Four Science Municipalities were selected for further study based on diversity in terms of their respective developmental stage as Science Municipalities. The background knowledge necessary for this selection was developed through earlier work on the Science Municipalities Project (Sølberg & Jensen, 2011).

As described, the challenge in mapping the social networks in the four selected municipalities was that the networks in question were at least partially hidden to us. Within each municipality, there is no comprehensive list of all actors involved in science education development to any given extent. These social networks were not based on formalised - but rather emergent - relational structures that resulted from a common involvement in different aspects of science education development. The MSE network traversed the municipal system and included members from the following organisational categories: informal learning environments, educational institutions, enterprises, the administrative and political level, and Other. In order to capture the wide range of actors constituting the MSE network, a snowball sampling approach was chosen for collecting SNA data. Snowball sampling is a respondent-driven sampling method used to reach unknown members of hidden social networks (Gile & Handcock, 2010). A web-based SNA questionnaire was constructed and validated by a group of test respondents representing the target respondent groups in the study. After this, the SNA questionnaire was sent to the MSE coordinator in each of the four selected Science Municipalities. The MSE coordinators were asked the following name generator question: "Whom within the municipality have you discussed development of science education with at least four times in the past year?" Actors named by the MSE coordinators - hereafter referred to as *alters* - received the same SNA questionnaire. When these alters named their respective alters, their answers gave rise to names of even more actors in the MSE network. This procedure was continued until the network was exhausted in the sense that maximum one or two new actors were mentioned in the most recent iteration of the sampling. In this way, the MSE networks were mapped and represented in sociograms by use of Pajek (de Nooy, Mrvar,

& Batagelj, 2005). The validity of network data was tested in follow up interviews with selected respondents by comparing the resulting sociograms with respondents' perception of the MSE networks and by building on qualitative data gathered previously in the SM project. The results showed that the sociograms were found to represent a valid picture of the MSE networks in the municipalities (for a full description of the sampling and validation procedure, see von der Fehr, Sølberg, & Bruun (2016 manuscript in review)).

### **Measuring Centrality**

We used three different centrality measures in order to identify central actors of the MSE networks: indegree centrality, betweenness centrality, and closeness centrality. Each is described in the following.

**Indegree centrality.** Indegree is one of the most intuitive centrality measures. It is based on degree, which is the number of actors who are adjacent to a given actor and with whom he/she is in direct contact with in the social network (Freeman, 1979). An actor's degree is thus the number of relationships the actor is involved in. The degree can be split into indegree, which is the number of relationships with the actor stated by others, and outdegree, which is the number of relationships the actor states to have with others in the social network. An actor can thus have a high indegree but low outdegree or vice versa. In the current study we chose to focus on the indegree rather than the outdegree, because it could indicate the actors who were considered relevant in science education. Based on the name generator question used in this study, the actor with highest indegree was the one whom most actors in the social network had discussed development of science education with in the past year. The degree of an actor has previously been related to communication activity (Freeman, 1979). It was therefore our assumption that indegree centrality indicated the actor's communication activity in the MSE network.

**Closeness centrality.** This centrality measure is based on closeness, which refers to the paths between actors. A path is a sequence of links (relationships) between two actors in a network and the shortest path linking two actors is called the geodesic (Freeman, 1979). An actor is central if the distances of all his/her geodesics are minimal (Freeman, 1979). This means that the actor with the highest closeness centrality has the shortest distance to the other actors in the network and therefore this actor has potential to influence many actors quickly without going through many intermediaries. An actor with high closeness may thus be more effective than others when communicating, because he/she is not dependent on others to distribute any given information. Closeness centrality has thus been related to communication independence and communication efficiency (Freeman, 1979). Closeness central actors in MSE networks were therefore assumed to be able to quickly distribute information to other actors whom they did not have relationships with in the social network.

**Betweenness centrality.** This centrality measure is based on betweenness, which refers to the frequency with which an actor is placed on the geodesic between two other actors (Freeman, 1979). Betweenness central actors can potentially facilitate or limit the flow of communication and resources between other actors in the network, because they are placed on the shortest path between many other actors in the network. This function of betweenness centrality is based on the assumption that information (or other resources for that matter) in networks always flow through the shortest paths, even though in real-life social networks information can flow through various paths (Stephenson & Zelen, 1989).

Betweenness centrality has thus been related to control of communication (Freeman, 1979). Actors with high betweenness centrality have been related to the ability to bring actors together and to control of resource flow (van der Hulst, 2011). In the context of MSE networks, a betweenness central actor was assumed to be able to mediate information between actors who did not have a known relationship with each other in the social network.

All three centrality measures were calculated for each network member (by use of Igraph software) and network members were ranked on basis of their centrality scores. This ranking served as the basis for selecting respondents for interviews.

### **Selection of Interview Respondents**

The actors with the highest centrality scores were selected for interviews. In case of indegree centrality, actors who were named in at least 25 % of the responses were selected. Only responses naming at least one alter were included in this context. In municipalities where no actor was named by at least 25 % of the responses, the actor with the highest indegree was selected. For betweenness and closeness centrality, the three actors with highest scores were selected. In cases where actors shared a high ranking (i.e. had same centrality score) all the high-ranking actors were designated for interviews. Actors were thus designated for interviews based on their ranking and not on their specific centrality scores. In other words, we did not define a limit as to how high the centrality score should be for the respondents to be selected. This strategy for selection of respondents was chosen because there is no fixed limit that defines when a centrality score should be considered high.

### **Constructing Interview Guides**

The overall purpose of the interviews was to explore how actors in central positions of the MSE networks described the way they contributed to the development of science education in the municipality. The first step was to check the extent to which the respondents acknowledged their central position. To this end, a number of confirmatory questions for each centrality measure were constructed based on descriptions of the different forms of centrality in the literature (see descriptions above). These questions were formulated so as to be recognisable in the respondents' daily contexts. Following, the respondents were asked to describe how they used the functions associated with their position in the social network to develop science education in the municipality.

## **Results**

All interviews were transcribed and analysed using codes based on interview guide themes as well as data-driven codes that emerged from the data. Codes referring to how central actors were able to contribute to development of science education in their network positions were collected in a cross-case analysis. The results were not exhaustive enough to allow broad generalisations about centrality. However, the results revealed patterns that may help to make qualitative decisions about how to distinguish between different functions in municipal networks, which are important for development of science education.

### **Indegree Centrality**

Out of the eight respondents with highest indegree centrality, six of them (75 %) confirmed that they fulfilled the functions associated with their indegree centrality. The respondents' answers were considered as confirmations if they affirmed that many actors discussed development of science education with them or if their estimate of the number of

actors discussing with them, did not differ with more than two actors from their indegree measure in the SNA data. Two respondents (25 %) did not confirm: one respondent estimated the number of actors to be much lower (10 actors) than the SNA data (16 actors), whereas the second respondent estimated the number to be much higher (30 actors) than the SNA data (9 actors). There is a possibility that these discrepancies might be caused by different interpretations of the name generator question in the SNA questionnaire.

The respondents, who confirmed that many people discussed development of science education with them, were asked how this function enabled them to develop science education. One advantage of having a high indegree, which was mentioned, was that to receive new ideas relating to specific issues and possible future initiatives. An actor with high indegree centrality could thus potentially facilitate mobilisation of resources by transforming ideas into projects and initiatives.

One actor mentioned he not only received new ideas but he was also able to distribute them. He continued: "In this way it becomes interesting to talk with me, if I have talked with others and have gotten new ideas". This points to two processes in opposing directions: one directed towards the high indegree actor and the other directing from the high indegree actor towards his alters. It showed that this respondent regarded the position of high indegree with some degree of reciprocity. However, while relationships are usually reciprocated, they are rarely symmetric (Wellman, 1983).

When asked about what the functions of her indegree centrality meant for her work, one respondent told that many of her relationships were with actors from schools and therefore her high indegree gave her information about what was going on in the schools of the municipality. This was also the case with another respondent, who added that actors from different organisations and hierarchical levels were necessary for educational development. This indicated that high indegree might be more valuable if the actor received input from other actors affiliated with different organisations and at different levels of authority.

### **Closeness Centrality**

Four of the nine respondents (44 %) with high closeness centrality confirmed that they were able to distribute information about science education to others by using their relationships with other actors to relay the information. Three respondents (33 %) confirmed this partially: one described that he was able to distribute information to some but not all schools; the second respondent described that in some cases she had doubts about whether the actors, that she had relationships with, distributed the information further on; and the third respondent described that she knew particular actors in some schools that she could write to in order to get information out, but she did not do this intentionally. One respondent did not confirm his closeness centrality and another respondent was too unclear to categorize.

We asked the respondents, who confirmed that they fulfilled the functions associated with their high closeness centrality, what they thought it took to be in a position where they could communicate effectively. It was indicated that in order to distribute information, it was necessary to have a thorough knowledge about the other actors and the hierarchical system. It became clear that some respondents used specific actors in the system to distribute information. These actors functioned as mediators and had key placements in the municipal system with access to many actors and/or influential actors in the municipality. Hence, they were described as actors with a function akin to high betweenness centrality. The mediators mentioned were actors in a position that were part of a formalised organisation of the municipal system, e.g. organised networks of science teachers and the MSE coordinator, or the internal organisation in the municipal administration. In one municipality, the MSE

coordinator (who was betweenness central) distributed information to school leaders through the Head of Education in the municipal administration, who was also identified as a member of the MSE network. The MSE coordinator was not allowed to visit the schools to give the school leaders information herself, but had to rely on the intranet for most communication. However, the Head of Education had subject-based meetings with the school leaders, and the MSE coordinator could pass on important information to the Head of Education in order to distribute it to the school leaders that way. The MSE coordinator hence used the intranet to reach the school leaders, when she wanted to distribute less important information e.g. information about science competitions, but she used the Head of Education when she needed the school leaders to engage in something. Despite having such an important role in the MSE network, the Head of Education did not score among the highest in the MSE network with regards to betweenness centrality. In the same municipality, a teacher described the MSE coordinator herself as a mediator of information. The teacher had the experience that the MSE coordinator passed on information to informal learning environments, the political level *and* school leaders. So interestingly, the MSE coordinator was considered as a mediator of information to school leaders by others, but the MSE coordinator herself had to use the Head of Education as a mediator to reach the school leaders. This suggests that the measure of closeness centrality did not register the potential bottleneck in the information flow in the MSE network.

Another feature, which was pointed out by respondents was that in order to distribute information effectively, it was necessary to have relationships with actors from different fields of subject (here math teachers) as well as actors who had a more ad hoc relationship with science education (e.g. librarians). This underscored the initial point that, in order to be effective in distributing information in the MSE network, the central actors needed a substantial knowledge of the other actors in the social network. But apparently, this knowledge of actors seemed to extend beyond the limits of the actors identified as part of the MSE networks. Diversity among the respondents' alters thus seemed to be important for high closeness centrality.

When asked about how they used their central position (in the form of closeness centrality) in their work, most respondents answered that they distributed resources as written information in the form of emails and communication on different kinds of intranets in the municipalities: "I have established groups on intra [school intranet in the municipality].... I can write directly to the groups on intra. I use that intentionally", "... I know who to write to in order to have an idea of whether they distribute [it] further in some of the schools", "... there has to be a hierarchy if I am not to spam all the teachers with mails every time there is a new notice". These quotes were from respondents in three different municipalities. It seemed that a lot of the information shared was written, rather than verbally transmitted, and distributed through digital media, which might not be surprising since these are common tools nowadays. Nevertheless, one respondent explained how she had to follow up her written communication with face-to-face-communication to make sure that her messages reached the recipient. She explained that teachers suffered from information overload: "... There are seven meters of paper stacked on every teacher's shelf, so they don't see that one [the piece of information from the respondent]. They receive ten offers a day so why should they choose that one [the offer from the respondent] exactly. They open eight mails after they have gone to bed at night and then they forget to respond...". It thus seemed that use of digital communication contributed to the information overload because it was so easy to send out information that way. This problem was also mentioned by another respondent. It is

interesting to posit that the function of the respondents' closeness position was threatened to some degree by information overload among their recipients, at least in schools.

The respondents described the different kinds of information they distributed in the MSE networks. Information about resources such as science education competitions, courses, special initiatives, announcements of new informal learning environments, national science tests, tips about science teaching, and practical information about projects and about application for funding were some of the examples. In other words, the shared information could provide access to otherwise hidden resources embedded among actors in the MSE network and could thereby contribute to mobilisation of resources, even if the information was not used by all the intended recipients.

### **Betweenness Centrality**

Seven (64 %) of the eleven respondents with highest betweenness centrality confirmed that they were able to mediate information between actors not otherwise connected. In one case, the respondent stressed that she only passed on information between other actors, who did not have a direct relationship to each other, under two special circumstances: during meetings in the administration and when she was physically present at the municipal education centre. This answer was only categorized as a partial confirmation, because the respondent indicated that the function of her betweenness centrality only played a minor and infrequent role. One respondent did not confirm having betweenness centrality, and the answers from two other respondents were unclear and could therefore not be categorised.

Respondents provided specific examples of situations where they made use of their position in the MSE network to mediate information between actors not otherwise connected. Based on the examples, two features seemed to characterise betweenness centrality. One feature was the ability to connect actors not otherwise known to each other. Some respondents with high betweenness centrality worked actively to connect actors physically (e.g. by arranging meetings), and by making unrelated actors aware of each other. By connecting others, the actors with high betweenness centrality could increase the number of relationships thereby increasing the density of the social network. This would make it easier for actors to access resources and thus increase the mobilisation of resources in the social network. The following striking example illustrated this: A teacher from a local municipal school called the municipal administration for advice regarding participation in a specific science project in the municipality. The administration staff contacted the MSE coordinator (who had high betweenness centrality) and informed him about the inquiry and in turn the MSE coordinator informed the teacher that another teacher working in the same school was already involved in the project. The MSE coordinator explained: "... it [the information] goes through me because they don't know who to turn to - because they don't know the other people [they meet in] the hall". The example demonstrates how this central actor helped connect actors from the same school. This can be considered as one way to facilitate mobilisation of resources embedded in a given school.

The other feature of betweenness centrality described in interviews, was the ability to distribute resources. When respondents described the distribution of resources, both tangible and intangible resources were mentioned, even though intangible resources were the most prominently mentioned. Examples were inspiration, information of existing activities (e.g. teaching projects), ideas and know-how, whereas the tangible resource mentioned in this context was teaching materials. The distribution of resources often crossed organisational boundaries. One example was a respondent who distributed information between an informal learning environment (a nature school) and a school. This was an example where the

respondent with high betweenness linked different organisations through her relationships with actors outside her own organisation. But what caught our attention in the analysis was that the distribution of resources in some cases crossed not only organisational boundaries but also hierarchical boundaries, in particular between educational institutions and the administrative and political level. This form of distribution posed special challenges due to the power relationships between levels in the hierarchy. One respondent emphasised that one of his key functions was to translate and transform information from educational institutions to the administrative and political level:

“... it is not me who has to make the decisions, but anyhow, I need to prepare it so that the leaders make the right decisions – so that it is being presented on the political level. Therefore it is not just about passing information on... It has to be reshaped in the reality of the administration, which means that something has to be made into proposals... and afterwards it needs to be implemented into the strategies... Just to pass information on does not change anything... I don't think that we just pass the information to and fro, because in the end we, as part of the administration, are the ones who have to act... it has to be implemented in a particular way which is [understood by] the administration and the political [level]... They [teachers] are not a part of that reality. They can come up with ideas, that have to be presented in a specific form and brought before the politicians”.

The link that this respondent constituted between practice and policy was described as necessary for the formulation of political strategies written in a language intelligible by actors at the administrative and political level. This indicates that actors with high betweenness centrality could potentially facilitate mobilisation of resources in the network by placing science education on the political agenda and aligning the needs in educational institutions with the strategies of action formulated at the administrative and political level. Resources, which could potentially be mobilised in this context, could be funding for development of science education or political attention to the development. Another respondent with high betweenness centrality described an example, where he increased school leaders' support for science education initiatives that were part of decisions made at the administrative and political level. Taken together, it seemed that some actors with high betweenness centrality were able to link different levels of actors and potentially help align policy and practice.

### Discussion

Different overall functions seemed to characterise the three centrality measures in the study. Respondents with high indegree centrality described how they received ideas from their alters. This could be interpreted as particularly relevant for science education development if the actors with high indegree had authority to implement new initiatives based on such ideas or if they could influence other actors, who had the authority to do so. Respondents with high closeness centrality used key actors as mediators to distribute information in the network, whereas respondents with high betweenness centrality connected actors, enabled distribution of resources or linked different organisational levels. Even though the confirmatory question for betweenness centrality pointed to the communication ability attached to these positions, the ability to connect actors (i.e. to bring actors together) was found in interviews with some respondents. This was consistent with the function described in the literature.

When comparing centralities, the results indicated that they differed from each other in terms of the way respondents used their position in the social networks to facilitate development of science education. Overall, the results indicated that the central positions

provided the actors with different possibilities to mobilise resources for use in science education.

The SNA data showed that it was primarily actors from the administrative level and educational institutions who scored highest in the three centrality measures. The data also showed that the central respondents were distributed evenly between these two organisational categories. Since there were a lot more actors from educational institutions than from the administrative level in the sociograms representing the MSE networks, the latter group can be considered as being more central in general. With only one exception, the MSE coordinators were the actors, who had the highest score for each centrality measure in the four MSE networks.

There was a significant overlap between the actors who scored highest in each centrality measure. This meant that a few actors in each municipality scored high on all measures indicating the tendency that the same key actors in the MSE networks (e.g. the MSE coordinators) seemed to have several functions as a consequence of their position in the social networks. This complicated the task of differentiating between the different centralities and their function, but each centrality measure was explored separately in the interviews using the confirmatory questions and further explorative questions based on the respondents' answers. The overlap seemed to have an amplifying effect on the actors' function and ability to mobilise resources for science education. While this has its advantages, one could argue that concentration of such functions on a few actors poses a potential threat to the MSE networks. If a central actor disappears from the network, it could cause significant decrease in opportunities for mobilising resources.

### **Conclusion and Implications**

Actors in central positions in the four MSE networks served a number of important functions that included receiving ideas, distributing information and other resources as well as connecting actors within the MSE networks. There were also indications that some central actors had an important function in aligning policy and practice. It seemed important that the central actors had opportunity to cultivate and maintain their relationships in the MSE network in order to maintain their functions. The study emphasises the importance of these central actors as their positions enabled them to mobilise various resources for science education.

Most of the central actors identified in this study were able to confirm that they fulfilled the functions associated with their central positions in the social networks and to articulate what the functions meant for their work. We suggest that knowledge of relational structures in such social networks might raise the awareness of how resources can be mobilised for development of science education. This again might facilitate actors' intentional use of functions associated to the central positions or enable them to change relational structures to improve their position in the network. Positions of actors with relationships across organisational and hierarchical boundaries within the municipal system seemed to hold particular promise as a way to increase alignment between policy and practice in science education development. This is considered as crucial for the coordination of resources and initiatives in development of science education and hence as a fundamental function for central actors in MSE networks such as the MSE coordinators.

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