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NETWORK WORKSHOP: USING NETWORK SCIENCE TO STUDY PROCESSES OF LEARNING

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Abstract: This paper describes the background for, realisation of and author reflections on a network workshop held at ESERA2013. As a new research area in science education, networks offer a unique opportunity to visualise and find patterns and relationships in complicated social or academic network data. These include student relations and interactions and epistemic and linguistic networks of words, concepts and actions. Network methodology has already found use in science education research. However, while networks hold the potential for new insights, they have not yet found wide use in the science education research community. With this workshop, participants were offered a way into network science based on authentic educational research data. The workshop was constructed as an inquiry lesson with emphasis on user autonomy. Learning activities had participants choose to work with one of two cases of networks. In the one case participants studied learning processes based on student interactions as represented by a social network. In the other they investigated how text represented as networks could lead to different interpretations of the meanings embedded in the original text. In both cases they created and analysed networks using the commonly used and freely available software *Gephi* (gephi.org). Reflecting upon why science education researchers might be hesitant to adopt network methodology we identify a key problem for networks in science education research: The cost in resources of learning how to include network methodology in one's research might supersede the perceived benefits of doing so. As a response to that problem, we argue that workshops can act as a road towards meaningful engagement with networks and highlight that network methodology promises new ways of interpreting data to answer questions about the processes of learning science.

Keywords: Network analysis, Assessment methods, Dynamic Visualization Tools, Evidence Based Approaches

BACKGROUND FOR THE WORKSHOP

Social Network Analysis (SNA) is a well-established field within sociology (Carrington and Scott, 2011), which educational researchers are beginning to utilise to investigate communities at various educational levels (Daly, 2010; Forsman, 2011; Bruun, 2012). Recently, networks have been used to investigate learning processes as they unfold in science learning contexts. For example, Koponen and Pehkonen (2010) used concept networks to investigate the quality and coherence of student knowledge structures. Bodin (2012) used networks of interview codes to investigate how students think about problem solving in physics before and after a teaching intervention. Networks have thus been used to represent cognitive aspects of student learning processes, but they have also been used to represent social and motivational aspects. Goertzen, Brewe, and Kramer (2012) show how the personal networks of three different students change during an introductory physics course and relate the network findings about the social aspects of becoming a physics student. Thus networks have been used to study social, motivational and cognitive aspects of learning.

The theory of networks is built around relations between entities, and they reveal structures of relations, which would not be visible without them. They have the potential to inform learning theories involving processes of learning, because they allow researchers to represent qualitative relations quantitatively. The only rule is that researchers need to be clear on what

the entities and relations (in network terminology: *nodes* and *links*) represent, and they need to continuously renegotiate their understanding of both entities and relations (Bruun, 2012).

With this workshop, we wanted to disseminate the practice of using networks in science education research. In our experience, networks are not easy to grasp. It is challenging to create networks, let alone to understand their message. However, networks offer fruitful ways of visualising, analysing, and interpreting learning processes in science classrooms.

Based on results from studies in science education that utilises network methodology, we believe that science education researchers can use knowledge of networks to change and understand learning processes and the systems in which they occur. Our aim with this workshop was to give science education researchers the opportunity to work with authentic data to create and analyse networks.

WORKSHOP CASES

Since we wanted to show the diversity of network analysis application, we chose two examples of networks, which are far from each other in terms of meaning, but can nevertheless be analysed using the same tools from network analysis. For this workshop, we chose a particular type of social and academic networks that are called student interaction networks (Bruun and Brewe, 2012) and linguistic networks (Massucci and Rodgers, 2006; Bruun 2012) as the examples. Here, we explain these network types, emphasising how they were constructed and how they could relate to the study of learning processes.

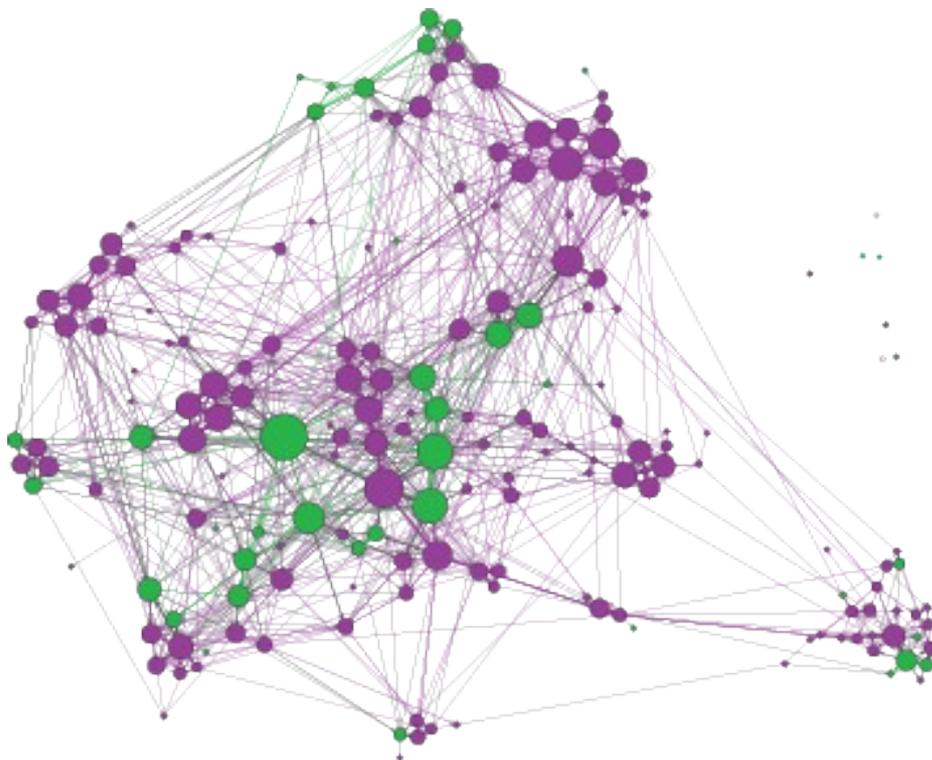## Example Case 1: Social and academic networks of student interactions

Figure 1. A student interaction network depicting how students remember having communicated with each other about problem solving. Student interaction networks are a type of social networks.

Figure 1 depicts the network for student interactions regarding problem solving in physics. The circles represent 187 students and the arrows these students' responses to the question: With whom do you remember having communicated with about problem solving in physics during the last week (Bruun and Brewe, 2013; Bruun, 2012). Each of the 1258 arrows represent the recall of interactions of this kind. The thickness of each of the arrows signifies that a student has remembered the particular student the arrow points to a number of times. The thicker the link (arrows) the more times a student has named another student. In Figure 1, gender is represented with colour (green for females, purple for males) while the number of links to and from each node is represented by the size of the circles. The exact procedure for developing questions and collecting data is described elsewhere (Bruun, 2012).

A network like the one in Figure 1 can be used in many different ways to study learning processes. First of all, note that networks have both a strong visual side while also being a mathematical object. This means that different measures of interest (for example, a student's position in the network) can be calculated and immediately visualised using different kinds of layout and geometrical and sensory attributes (size, shape, and colour). Second, a link can represent processes of learning, because it implies that an interaction has taken place between two students (Bruun, 2012) and network position may be seen as a proxy measure of participation (Goertzen et. al, 2012; Dawson, 2008).

In Figure 1, it seems that some clusters of circles are closer together than others. For example, to the far right, there is a cluster representing students that seems to be only loosely connected to the rest of the students. If one looks even more closely, other clusters of students can be discerned. For example, the top right cluster could represent a group of students. Bruun (2012) have suggested that such clusters of students might represent communities of practice or even communities of learners (Wenger, 1998). One way of using a network in research on communities of practice could be to use them to identify candidate communities, which one could then investigate by other methods, for example interview or observations[1].

Example Case 2: Amplified linguistic network of the PISA 2015 definition of Scientific Literacy

Figure 2 shows a linguistic network representing the proposed definition of scientific literacy from the PISA 2015 framework (OECD, 2013, p.7). The network has been created using a coding scheme that reduces single complex sentences to many simple sentences (Bruun, Evans and Dolin, 2009; Bruun and Nielsen, 2013)[2]. The principle can be seen with one sentence from the definition: "Recognise, offer and evaluate explanations for a range of natural and technological phenomena" which is parsed into the sentence parts:

1. Recognise explanations for a range of natural phenomena
2. Recognise explanations for a range of technological phenomena
3. Offer explanations for a range of natural phenomena
4. Offer explanations for a range of technological phenomena
5. Evaluate explanations for a range of natural phenomena
6. Evaluate explanations for a range of technological phenomena

In this case, action verbs are separated to make the connection between each verb and the word *explanation* recognisable in a network. For the same reason natural phenomena and technological phenomena are separated. The connections become clear in the network since

an arrow is drawn between two words, if they are adjacent in the parsed text. That is, since *explanations* follow *recognise* two times the parsed text will give rise to an arrow of thickness two in the corresponding linguistic network.
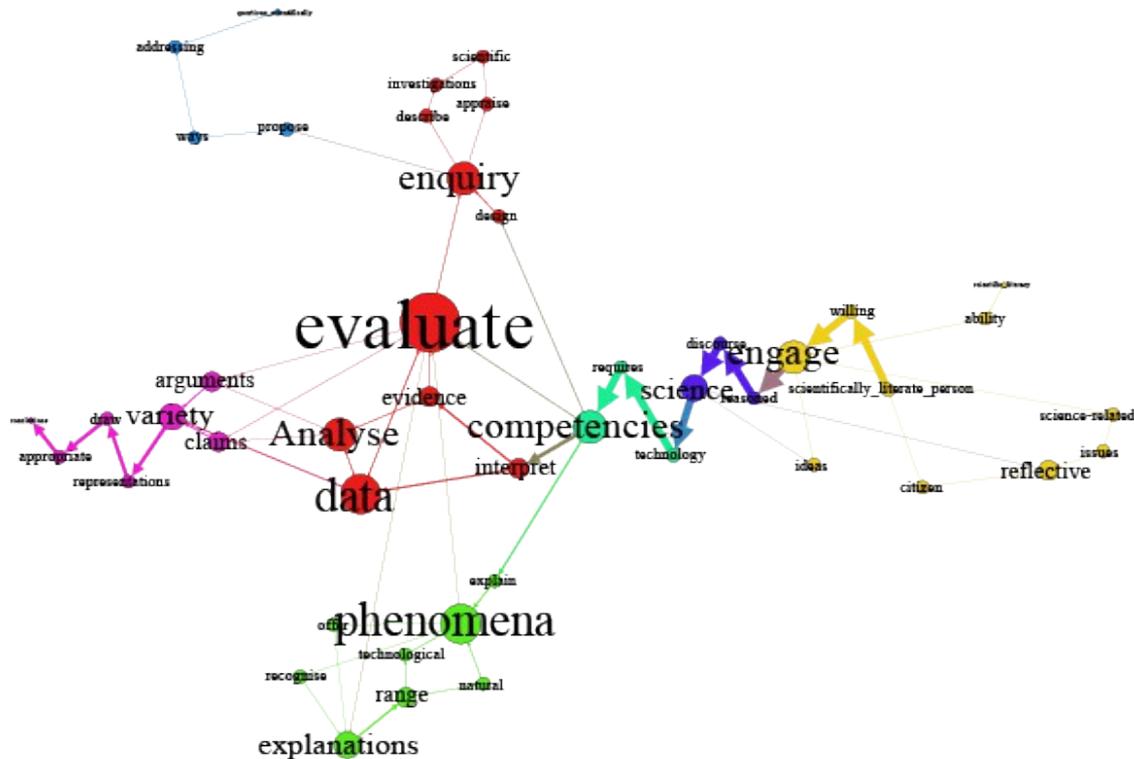

Figure 2. An amplified linguistic network which represents a text. Each circle represents a word, and words are linked according to a particular coding scheme.

 Following standard text mining principles (Feldman and Sanger, 2007), common words like *for* and *and* are removed and if necessary, words are reduced to a stemmed form (*explanations* and *explanation* is represented by the same word). In Figure 2, the size of the nodes are proportional to the PageRank (Brin and Page, 1999) of the word in the parsed version, and colours represent groups of words as found by a computer algorithm developed in network science to detect communities in networks (Blondel, Guillaume, Lambiotte, and Lefebvre, 2008).

An amplified linguistic network like the one shown in Figure 2 is related to the study of learning processes since it highlights a particular view on what OECD has deemed important for students to learn as part of school. In this view, *evaluate* is the central verb pointing to *enquiry*, *arguments*, *claims* and *explanations*. In contrast, *interpret,* is less central, and actually indirectly links to *evaluate* through *data* and *evidence.*

The network in Figure 2 is an instance of a linguistic network that maps a text, which happens to be an official document. But one could also map student texts on a science subject at different times to see how they connect different words in different ways during a course (Bruun, 2012). This is a different situation, which may require different parsing and text mining procedures. However, it would be directly linked to student learning processes.

Using both the parsing technique described above and applying the principles from text mining has important theoretical consequences (Bruun, 2012). For example, one could argue that the artificial amplification may not represent the true meaning of the document, or that

words that are common in everyday language might have special meaning in science contexts and conversely that words that are not often used in everyday language could be abundant in science texts. However, these considerations are not methodological shortcomings but rather choices that one should be aware of. These choices allow researchers to study texts in different ways and from different perspectives.

DESCRIPTION OF WORKSHOP

We wanted the participants of the workshop to experience some of the issues and possibilities that we have experiences with when working with networks. To facilitate this, we used a hands-on inquiry based approach (Lawson, 2007).

In the workshop, participants downloaded and used *Gephi* software to investigate and create networks of the two types exemplified above[3]. These networks were based on authentic research data supplied by the authors. After a short introduction, they chose to either create a linguistic network based on the proposed PISA 2015 definition of scientific literacy or to investigate different kinds of student interaction networks. Facilitator explanations were kept to a minimum; the role of the facilitators was to validate practices and help with technical difficulties. Table 1 illustrates the detailed plan.

Table 1

Schema of the activities in the workshop.

Title	Activity	Concepts	Products
The goals of the workshop	Prezi presentation	Networks of words, networks of people	Prezi at www.prezi.com
Preliminary tasks	Exploring networks using *Gephi*	Linguistic networks, social networks, basic features, meaning of networks	Different layouts of provided networks
SNA/LNA task	Exploring social/linguistic networks	Centrality, importance, community detection, continuous development of meaning	Participant developed networks
Summing up	Plenary discussion	Using networks, qualitative/ quantitative/mixed research	Ideas in Prezi

Since we saw the workshop as a teaching/learning activity, we structured it as such. The workshop learning objectives were for participants to:

1. Make an informed choice of one of two cases of using networks based on short initial presentations and preliminary tasks.
2. Create and visually analyse a network from real data using commonly used and free network analysis software.

It is our impression that participants did in fact meet these learning objectives. We base this on the discussions we had with each participants (Goals 1. and 2.) and on the fact that we could see participant progress (Goal 2.).

The workshop emphasised particular realisations of how one can study learning processes with networks. However, educational researchers might also study learning processes (and indeed other phenomena) by representing coded texts and transcripts as networks (Bodin, 2012; Bruun, 2012), or by making similarity networks on questionnaire data where two respondents are connected if their answers are similar (Elmeskov, Bruun, and Nielsen 2013). These kinds of networks can help researchers structure their data to find patterns of interest that they would not see otherwise.

REFLECTIONS ON NETWORK WORKSHOPS

The authors believe that networks hold great potential for informing science education research as a field. However, many researchers seem hesitant to embrace them as a research tool, which we attribute to two things. First, while networks seem to intuitively be meaningful when presented in a paper, any detailed investigation of them quickly becomes very complex. Second, networks offer a new way of thinking about data collection and analysis, and it is often not straightforward to see how network analysis could bring additional useful meaning to a particular area of research.

Taken together, these two reasons seem to lead to the following problem for networks in science education research: The cost in resources of learning how to include network methodology in one's research might supersede the perceived benefits of doing so. It remains a task for current network users in science education research to show the possibilities of working with networks and to develop ways for other researchers to engage with networks.

We believe that, one of the roads towards meaningful engagement is through workshops. In this particular workshop, participants explored two networks that were qualitatively different. However, as argued in the Introduction, many other kinds of networks can be created to yield very diverse types of information about learning processes. From a constructivist point of view (e.g. Lawson, 2007), participants would gain the most from working with data that is close to that with which they normally work. In that way, each participant would clearly be able to see the correspondences between network representations and the representations with which they normally work. Following this line of thinking, network workshops that target not only methodologies but also different research interests should be developed and held.

The network software *Gephi* that we used for this particular workshop has many advantages. First of all, it is free and can be downloaded to every major operating system (Mac, Linux, Windows). Second, it has a visual and dynamic interface that can illustrate many aspects of network science models and representations. Third, it offers algorithms for calculating numerous network measures, which can then be illustrated graphically. Finally, the software code is open source and supported by an extensive online community. Thus, many extensions are available for many different purposes. For more extensive work, other software programs, like R[4], offer more powerful ways of analysing networks. However, the visual aspect of *Gephi* along with its many functionalities, make it a valuable tool for research.

Network workshops might hold the potential for academic discussions that can help science education researchers develop network methodology as it could be applied in research aiming at changing teaching. As shown in Figures 1 and 2, networks have a visual side that can clearly show the structure of related entities. One could imagine studies in which certain kinds of teaching strategies that were based on research on learning processes, were

employed. Different strategies might result in different networks, for example two different social networks or two different linguistic networks. Discussions at workshops could serve to develop validity and interpretation of such networks.

Network methodology as employed in science education research involves collecting data in ways, which resemble other kinds of data collection in the field. Transcripts of interviews, annotated video, texts of varying types, and survey data have been represented and analysed meaningfully as networks. Network analysis does not require that researchers collect raw data, like video, text, and audio files in new ways. However, the preparation of data involves converting the raw data to entities, which are related to each other. That is the data must have the form of a set of nodes and a set of links that connect the nodes. If this criterion is met however, network methodology seems to promise researchers new ways of interpreting data to answer questions about the processes of learning science.

NOTES
1. This particular idea was developed as part of one of the author's discussion with a participant in the workshop.
2. A detailed procedure is given at https://absalon.itslearning.com/jbruun/blog/.
3. The task sheets and network files used for the workshop are available at www.jbruun.org/ESERA2013
4. Available at http://r-project.org

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