Measuring Integrated Knowledge – A Network Analytical Approach

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Abstract: Scientific literacy is an important part of education. Students that demonstrate scientific literacy can organize and coordinate their science ideas to interpret and explain a diverse range of phenomena. However, the complex thinking connected to this ability is not captured by most assessments today. We address this issue by investigating how the little researched construct of knowledge integration which describes how students coordinate their ideas in explanations can be measured using network analysis.

Measuring what matters

A central goal of education is to prepare students to act independently and responsible in society and the world. In a world increasingly dominated by science and technology, scientific literacy is an important part of this education (National Research Council, 2012). A key component of scientific literacy is students' ability to use their knowledge about science to interpret and explain phenomena in diverse real-life contexts. To explain real life phenomena, students must be able to produce coherently organized accounts by coordinating a range of relevant scientific ideas with evidence. As Schwartz & Arena (2013) argue, assessments of scientific literacy should measure how well students are prepared to do so. However, instead of measuring how much students are prepared to engage in complex thinking, i.e., to what degree they are able to coherently organize relevant ideas, most current assessments focus primarily on how much knowledge students have acquired (Pellegrino, Chudowsky, & Glaser, 2004). The ability to coherently organize relevant ideas is emphasized in the knowledge integration perspective on learning (Linn, 2006). It focuses on how students develop increasingly more coordinated networks of ideas, i.e., ideas are added, new connections established, and others are refined. Students that have a coherently organized knowledge can rely on strongly developed idea networks that allow them to explain real world phenomena by coordinating relevant ideas.

Measuring knowledge integration

Although knowledge integration is important for the development of scientific literacy, there is little consensus on how best to measure it. A number of cross sectional studies used different approaches to measure knowledge integration. While Lee & Liu (2010) focused primarily on the number of connections between ideas and the quality of these ideas that students use to explain phenomena, Nordine, Krajcik, & Fortus (2011) operationalized integrated knowledge as students' ability to consistently use central ideas across a range of phenomena. This illustrates that there are different perspectives on measuring knowledge integration that focus on different aspects of the construct while leaving out others. For example, the holistic measure of the extent to which students connect ideas used by Lee & Liu (2010) does not provide information about *which* ideas are most central to students' thinking or the relative strength of connections between ideas. However, this is helpful information for educators to, for example, adjust teaching or helps to improve curriculum. We address this issue by using network analysis to characterize the extent to which students' ideas are well-integrated and how the strength and coherence of connections between ideas changes during instruction. As this research is part of a broader project on the teaching and learning of energy, we ask the following research question: How can network analysis be used to more fully measure and describe the extent to which students possess integrated knowledge of energy?

Methods

A unit on energy was implemented in 7th grade at two schools in the US with N = 311 students. The teachers selected a sample of N=30 students that are representative sample regarding grades. Students were interviewed before and after the unit using semi-structured interviews in which students were presented 5 different phenomena from everyday life, e.g., a bouncing ball. The students were asked "How would you explain this phenomenon?". The interviewers then used non-instructive probes to clarify students' answers. Using qualitative content analysis, we coded which ideas students used to explain the phenomena (inter-coder reliability $\kappa = 0.87$). In a next step, we analyzed which ideas students used in the explanation of a single phenomenon. We then created maps of co-occurrence of ideas across phenomena. The resulting dataset is a network that can be analyzed on individual and aggregate level for each of the measuring time points using network analysis methods (e.g., Grunspan et al., 2014).

Results

The following preliminary results are based on the analysis of interviews from 17 out of the 30 students in our sample. Based on background measures such as grades etc. we do not expect the full results which we will present at the conference to change significantly. Figure 1 shows the aggregated pre and post networks. The ideas used by students are depicted as circles where the size of the circle represents the number of co-occurrence with other ideas. The lines between the circles represent that two ideas occurred together and the width of the lines shows often those ideas were used together. From pre to post we see a substantial development concerning which ideas co-occur and how often they co-occur. The energy unit used in this study emphasizes energy transfers and fields between objects, and we see that those ideas are used increasingly more often with other ideas and that the number of those co-occurrences has increased after instruction. Energy transfer has become a more central idea during the unit as it becomes strongly connected with many other ideas. To what extent those connections are coherently organized can be investigated using a coherence measure from network analysis (see e.g. Koponen & Huttunen (2013)). We find, that the post network as a whole has become more coherently organized. We used the pre to post difference in this coherence measure to predict the pre to post difference on a test that assesses how well students can use energy ideas to interpret and explain phenomena. As a validity check, we used Bayesian methods to fit a linear model that predicts the gain on the energy test using the gain on the coherence measure. The standardized coherence regression coefficient has a value of β^2= .6 [.2, .9] [89% probability interval] and R^2=.34

Discussion and outlook

Concerning our research question, the presented networks show that network analysis has the potential to show how students integrated knowledge develops over time, e.g., the analysis shows that students develop an integrated understanding around the central idea of energy transfer and to a lesser degree integrate the idea of fields. Further, we interpret the strong relationship between the coherence measure and performance on the energy test that asks students to use energy ideas to make sense of a range of phenomena (not part of the interviews) as evidence that the approach is valid. Based on these results, we consider network analysis of integrated knowledge a promising approach to provide insight into not just whether, but how, students use a range of science ideas to make sense of the world. We feel that ICLS 2018 provides an excellent opportunity to share what we believe is a promising method of assessing integrated knowledge and to discuss potential improvements with other researchers.

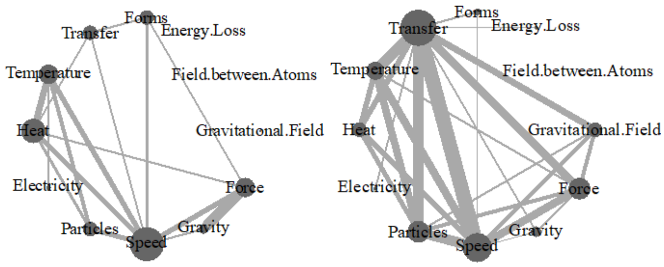

Figure 1. Aggregated idea networks pre (left) and post (right).

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