Network Analysis Of Changes To An Integrated Science Course Curriculum Over Time

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*Curriculum texts for science courses change over time as policy changes. Changes occur in particular wordings in official documents and give rise to changing possible interpretations. Using a recently published methodology, the study from which this paper reports, constructed thematic maps of the development of the curriculum for the upper secondary Danish "Basic Science Course". The analysis integrates qualitative analysis (critical discourse analysis) with quantitative analysis (linguistic network analysis) to identify and characterise themes in official curriculum texts for the course. This chapter provides illustrative examples of the methodology, a discussion of our methodological choices, and the findings of the study. We analysed curricular texts from 2004 (first curriculum text), 2007 (first change), and 2010 (second change). We focused on four themes, emerging themes: Structural Demands, Implementation of Teaching, The Importance of Science in a Bildung Perspective, and BSC’s Identity as a Course. The findings show that Structural Demands changed little over time; the didactical focus remained on "active learning". Implementation of Teaching first appeared as a theme in 2007 and matured in 2010 to be linked to the identity of the course as well as the goals for competences to be learned. Finally, we found that The Importance of Science in a Bildung Perspective started out as a separate theme but merged in 2010 to become integral to the purpose of the Basic Science Course. This may signify a maturation of the course to represent a school discipline in its own right. It may also imply an official intention that science should be part of most students' development as citizens. The chapter discusses the appropriateness of thematic maps as analytical tools how these curricular analyses can be linked to the political discussions amongst stakeholders.*

*Keywords*: Curriculum, Nature of Science, Interdisciplinarity

Introduction

Official educational documents often reflect an agglomeration of political intentions at a given time and may change in light of educational policy changes (Akker, Fasoglio, & Mulder 2011; Schmidt, McKnight, Valverde, G., Houang, & Wiley 1997; Priestley & Biesta 2013; Dolin & Evans 2018). The wording of particular curriculums can influence the perceived possibilities for teachers in implementing new curriculums. For example, Evans & Dolin (2018) found that many science teachers had little experience with reading official documents and therefore did not see how different notions of scientific literacy were emphasised on these documents. They found that a conceptual network tool – a tool which relied on linguistic networks (Mehler, Lücking, Banisch, Blanchard, & Job 2016; Bruun, Dolin, & Evans 2009) – could alleviate teachers’ negative experiences by highlighting important themes and “less apparent interrelationships and relative emphases of various aspects of […] scientific literacy” (Evans & Dolin 2018). The conceptual network tool presented by Evans & Dolin represented words and connections between words in official conceptualisations of scientific literacy. The goal was to help teachers identify themes and patterns in the intended outcomes for scientific literacy in different European countries in order to implement and realise these intentions in teaching. Their work highlights that even if curriculum texts can be seen to include specific intentions, teachers may not acknowledge or even be aware of these intentions. This may in part be because of a persistence of earlier developed practices (e.g. Akker et al. 2010; Verbiest & Erculj 2005) but can be alleviated by working to achieve a deeper understanding of themes in curriculums.

In general, analysing themes that emerge in official documents may play an important role in understanding the interplay between intentions, implementation and attainment of teaching. Akker et al. (2010) develops a framework, which they use as a basis for addressing overarching questions about how student learning is envisioned. The framework addresses ten components: rationale, aims & objective, content, learning activities, teacher role, grouping (of students), location, time, and assessment. We argue that in addressing such components, a variety of themes might emerge in curriculums over time that could be seen to reflect different stakeholders’ emphases and perhaps conflicts between different views. Inspired by Akker et al. (2010), we argue that intentions, implementation, and (observed student) attainment may influence each other over time. Thus, teacher implementation may not reflect intentions in a curriculum (as stated by Akker et al. 2010). This might be ignored, be addressed in teacher professional development, or lead to a change of wording in the curriculum. Likewise, observations about student attainment might influence curriculum development to change standards or suggestions for pedagogy. In this paper, we show examples of such emerging and developing themes as they appear through the lens of a newly developed network analytical method (Bruun, Lindahl, & Linder 2019).

As an illustrative example, we use different versions of the official curriculum for a Danish integrated science course. Our aim is both to summarise emerging themes, to visualise connections between themes and development of themes through time.

Intentions in the Danish ‘Basic Science Course’

In many countries, ideas of inquiry and scientific literacy have been woven into national curriculums (e.g. Evans & Dolin 2018). Often, inquiry-based science teaching, understood as science teaching in which students are motivated to engage meaningfully and autonomously with scientific content to construct knowledge and draw conclusions (e.g. Minner, Levy, & Century 2010), is seen as a pedagogy that can help students achieve scientific literacy. Germany and the Nordic countries often also see scientific literacy in relation to Bildung perspectives; here, science is also important to a person’s understanding and experience of their relation to the world and society (e.g. Ropohl, Nielsen, Olley, Rönnebech, & Stables 2018).

In Denmark, ideas of scientific literacy, inquiry-based science teaching, Bildung, and interdisciplinarity were implemented officially in the largest of the country’s four national upper secondary programs (called *stx*) in 2004. This was done through the introduction of the Basic Science Course (BSC, “Aftale af 28. maj” 2003). The curriculum text was changed in 2007 and 2010.

One of the intentions of BSC is to introduce students to science through work with the basic elements of natural science. The focus should be on the commonalities and the differences within the natural science disciplines (DME 2013). BSC teaching is meant to consist of exemplary and contemporary thematic issues where the scientiﬁc disciplines are required to work together using some degree of interdisciplinarity (Jantch 1972).

Another objective of the BSC is to make the students aware of the importance of knowing and understanding scientiﬁc thinking. This objective should be reached in order to make the student able to reflect on the strengths and limitations of scientiﬁc knowledge. Moreover, the students also have to achieve knowledge about a central scientiﬁc issue which supports their curiosity and commitment for natural science and encourage them to learn more about science (DME 2013).

The course has been the source of public debates and has been evaluated with respect to – among other things – the perspectives above (Dolin, Jacobsen, Jensen, & Johannsen 2016). As such, we may expect themes regarding, for example, scientific content, aims, teacher roles, and structure should emerge. However, we do not know the details of the themes, which tensions (if any) themes may harbour, or how themes may be connected. Thus, we argue that the BSC curriculums from three different years comprise a worthwhile illustrative example of our proposed way of analysing curriculums.

Research questions

This chapter reports on a larger study conducted in 2016-2017 (Andersen 2017). For the purposes of this illustrative example, the research questions are:

1. Which interconnected themes emerge as prevalent as in the Danish BSC curriculum texts for years 2004, 2007, and 2010?
2. How do selected themes evolve through years 2004, 2007, and 2010?

Methodology

The complexity of educational systems (Evans et al. 2018) can be seen to warrant an integration of quantitative and qualitative perspectives into a mixed methods design (Roberts & Onwuegbuzie 2004). This also holds for analysis of educational policy. Bruun et al. (2019) recently combined qualitative discourse analysis with linguistic networks in a mixed methodology for transcripts of group discussions called thematic discourse network analysis (TDNA). The analysis revealed and graphically displayed hidden themes to provide a nuanced and rich picture of the data. Bruun et al. (2019) analysed group discussions and used qualitative discourse analysis to the discussion into conversation units, where each unit “should appear to be a distinct part in the sense that it ends as the conversation is exhausted […]” (p. 325). In contrast, this study relied on official documents, which are related to different discursive and social practices (i.e. the practices of politicians, document authors, the teachers who’s teaching the documents concern, the leaders of these teachers, and other stakeholders, such as researchers and industry). Critical discourse analysis (CDA, e.g. Fairclough, Muldering, & Wodak 2011) is well suited for analyzing such documents in light of different discursive and social practices. For example, Fairclough et al. (2011) reports that CDA has been used with computer-based analyses of keywords to analyze historical developments of UK political discourse. This combination of CDA and keyword analysis has demonstrated its “heuristic value in directing the analysts’ gaze in unexpected and often fruitful directions” (p. 366). Here, we first show how we used critical discourse analysis, and then proceed to show in short, how we employed TDNA. The following sections follow Andersen (2017), which also contains detailed descriptions of the methodology.

Critical discourse analysis in the present study

We used Fairclough’s three-dimensional approach (Fairclough 1993), where a (here written) text is seen as an instance of a discursive practice, which involves production and interpretation of texts, which is in turn part of a social practice with social structures and power relations. Inspired by Fairclough (1992), Figure 1 presents a graphical representation of how we see official Danish BSC curricular texts as embedded in discursive and social practices.

A screenshot of a cell phone

Description automatically generated

Figure 1. Illustration of the curriculum for the Basic Science Course (BSC) in Fairclough’s three-dimensional framework. From Andersen (2017).

In the analysis of the curriculum text, Fairclough’s approach is oriented towards linguistics, as, for example, vocabulary, commonly used phrases and passages have an impact on discursive practices, for example, teachers’ interpretations, and social practices, for example, teaching practices. For us, the aim was to find themes that may characterize intentions for teaching in curricular documents. The aim for us of linking to discursive and social practices was then to link between the text and possible processes of interpretation and use of the text.

Thematic discourse network analysis of curricular documents

Using thematic discourse network analysis (TDNA) to find interconnected themes in the BSC curricular documents begins with using CDA to find candidate themes. In parallel, we converted each BSC curriculum document into a linguistic network (Bruun et al. 2009, Andersen 2017). In such a network, nodes represent words/phrases, and connections (directed links) represent adjacency and order of appearance in the text. For example, the phrase *students should learn* would be represented by three nodes and two arrows: *students -> should -> learn*. Then, in each network, we used a network clustering algorithm called Infomap (see e.g. Bohlin et al. 2014), to find clusters of words (Andersen 2017; Bruun et al. 2019). In these networks, words shared connections within the cluster it is part of as well as outside of that cluster. On average though, words within a cluster shared more connections than they did with other clusters. Because words shared connections with other clusters, we were able to make maps of how clusters for each linguistic network were related. Thus, we were able to make candidate maps of each iteration of the BSC curriculum document. In these maps, each cluster represented a candidate theme, which could be scrutinized by analysing the connections in the cluster. This enabled a crucial step in the TDNA methodology; comparing and contrasting the candidate themes, which could be identified in the network maps, with candidate themes, which were identified using CDA. We found that on the one hand, some CDA themes was either not found as themes in the network maps or we could only make a weak argument of correspondence. On the other, some themes emerged from the network maps, which we thought of as relevant, but which were not part of the initial CDA. This led to both changes to network analysis and to new interpretations in light of the CDA. Having made new networks and network maps, the process was repeated in order to reach alignment between network maps and critical interpretations. The final products were a set of networks, network maps, where clusters represented themes, and an interpretation of these themes in light of the Danish upper secondary education.

Discussion of methodological choices

TDNA is a novel methodology, which merits a discussion of our methodological choices in this study. The methodology can be seen to have three modes: the qualitative analysis (here CDA), the linguistic networks, and the thematic maps. For this study, we chose CDA as the appropriate qualitative framework. For other studies, other qualitative frameworks may be appropriate (see e.g. Bruun et al. 2019).

It is possible to integrate advances made in the field of text-mining, such as stemming, lemmatization, part of speech tagging, and tokenization (Feldman & Sanger 2007) in TDNA. These fields rely on large sets of texts to define general rules for, for example, automatically reducing all forms of a word to a single basic form and removing prefixes and suffixes (stemming). However, we argue that in analyzing specialized texts, such as curricular texts for a scientific curriculum, the general rules developed in text-mining literature may cloud or remove aspects of meaning (Bruun et al. 2019), which in TDNA are important in the iterative development of our understanding of the texts through CDA, networks, and maps. Therefore, any use of these advancements should be monitored with care throughout the process.

We chose to use directed networks in this study, but a case could be made for using undirected networks: If the order of nodes (here, words) in general carry no meaning, then enforcing directionality could induce misleading structures. In using a directed network rather than an undirected network, we follow Masucci & Rodgers (2006), who both argue and show empirically that the order of words is an important property of human language for creating meaningful sentences. This has practical implications during the analytical process. TDNA involves continuously scrutiny of linguistic networks in relation to the original text. With directional links, it is possible to discern much of the original text in the linguistic network by following links. We argue that this reading of the text in the network provides a crucial connection between network representations and original text. The directionality of links is mirrored at the thematic map-level, where it signifies at tendency of words in one module to follow words in another. Bruun et al. (2019) uses this to identify how stages of argumentation in a student discussion followed each other. In this study, we do not pursue the meaning of the direction of directed links at the map-level, but refer instead to Andersen (2017) for possible interpretations.

Many network clustering algorithms are non-deterministic and may in some cases produce variations in clusters in subsequent applications of the algorithm. However, Lancichinetti & Fortunato (2009) shows that Infomap is a robust choice for clustering. Even so, strategies for addressing variations exist. For example, Bruun & Evans (2020) apply Infomap 1000 times and subsequently use the most frequently appearing set of clusters. We used Bohlin et al.’s (2014) framework to apply Infomap on our linguistic networks numerous times, and did not find variations in clustering for the linguistic networks used to create the final thematic maps.

Findings

Central themes in the analysed curriculums and their interpretations

This study revealed 13 different themes across the three years. Each theme is constituted by a number of connected words and network maps show linguistic connections between themes. Figure 2 shows the network map for 2010. Each circle on Figure 2 represents a particular theme as produced by our TDNA. For instance, the circle with the label *Importance of Science in a Bildung perspective and the BSC* represents one theme that we identified in 2010. Each theme has internal network structure based on connections between words in the curriculum. The right-most network on Figure 3 shows the internal network structure of the theme *Importance of Science in a Bildung perspective and the BSC*, which we identified in 2010. On Figure 3, the circles represent words used in the curricular text, while arrows represent connections as described in the previous section. The arrows in Figure 2 represent connections at the word-level between themes. Thus, the light blue arrow from *Implementation of teaching* to *Importance of Science in a Bildung perspective and the BSC* represents, for example, a connection between “completion” in the former theme and “experimental [activities]” in the latter.

As stressed above, the network map shown in Figure 2 as well as the networks on Figure 3 are *only* parts of theoutput of TDNA. Our interpretations and maps and networks are complementary to each other, and neither can stand alone. To illustrate, we will provide short versions of our interpretations of the overall map of 2010 and of four of the more prevalent and central themes which emerged from our TDNA of the curriculum for years 2004, 2007, and 2010. We briefly show how themes can be connected to Fairclough’s discursive and social practice dimension (see Figure 1) by relating them to relevant studies of policy and teacher practice. Our TDNA shows that two of the four themes, Themes 11 and 13, merge over the course of three versions of the curriculum. We illustrate this merger by showing the evolving network structure of the two themes (see Figure 3), while we do not show the network structure for the remaining two themes.

In our interpretation, the network map for 2010 shows that the BSC is intended to stage science as part of Bildung: Importance of Science in a Bildung perspective is central, with many arrows pointing to and from it. The arrows that emerge from this central theme can be interpreted as a specification of *how* science should be seen as part of Bildung: It entails for the students to develop an *Experimental approach to the world* as well as a *Perspective on society and technology*. This is then reflected in the *Competences to be learned*. In terms of teaching, the incoming arrows can be seen as specifications to how to teach. There are *Structural demands to the BSC*, other demands for *Implementation of teaching*, *Demands to the academic content* of the course, and specified demands for how students should work with their *Writing competencies*. Interestingly, students’ work with the *Scientific method* and *Hypotheses* are part of the overall conception of the BSC but not directly linked to the Bildung perspective.

Theme 10 (Structural Demands to the BSC) represents the preferred way in which the BSC should be taught. The network structure of the theme revealed that teachers are expected to emphasis on thematic modules. In all three curricula, interdisciplinary aspects are also addressed here. In terms of linking this finding to social practice, the presence of this theme may highlight a tension between curricular intention and teacher practice. Danish teachers who work with thematically structured and interdisciplinary teaching find that, for example, time and collaboration pose obstacles to realising these demands (e.g. Elmegaard, Bruun, & Nielsen 2015).

Theme 11 (Importance of Science in a Bildung Perspective) is prevalent in all curriculums. The focus here is on development of students as persons who can reflect on science as they take part in society. This focus has strong links to both the Danish Bildung perspective as well as scientific literacy discussions (Evans & Dolin 2018). Political discourse in Denmark emphasises the Bildung aspect in upper secondary schooling, and Danish upper secondary teachers find that this aspect is an important part of their practice (e.g. Dolin et al. 2016).



Figure 2. The thematic map for BSC curriculums from 2010. Themes from Table 1 in bold. Note that Themes 11 and 13 merged to a single theme in 2010 as explained in Evolution of Themes. Thus, only three themes are in bold in this map. The sizes of circles signify the prevalence of the theme of the constituent words in themes. The sizes of arrows reflect the tendency of words in one cluster to connect to words in another cluster. See Andersen (2017) and Bruun et al. (2019) for details. Visualisation made with MapEquation (see Bohlin et al. 2014).

Theme 10 was connected to Theme 11 in all the analysed curricula. This may signify an intended connection between how the course is taught and how students should develop as human beings. Interestingly, Theme 12 (Implementation of Teaching) appears for the first time in 2007 and specifies in more detail, how teaching should be conducted (e.g. making observations, using themes as a basis for experimentation). As such, it could be seen as an elaboration of Theme 10, although only few linguistic connections appeared between the two. Thus, the curriculums seemed open to teacher interpretations of how different student activities were meant to support, for example, interdisciplinarity and the use of thematic topics.

Theme 13 (BSC Identity as a Course) conveys how the BSC should be construed as a school subject in Danish upper secondary schools. It should be seen as an introduction to the natural sciences and how these and their methods are related to each other. Linking natural sciences and different methods and models used in natural sciences may have a profound impact on teachers’ practice, if teachers are used to focus only on one scientific school discipline at time. For example, Andersen (2017) also observed teachers’ implementation of the BSC and found that most of the observed teachers predominantly addressed one scientific school discipline in their teaching. Table 1 summarises these themes.

Table 1. Themes identified in thematic maps.

|  |  |  |
| --- | --- | --- |
| **#** | **Theme** | **Summary of interpretations (quotes are our translations)** |
| 10 | *Structural Demands to the BSC* | Focus on student activity, thematic topics and pluridisciplinarity. Sample wording belong to this theme (2004): *"the BSC implementation should be based on thematic topics which are preferably pluridisciplinary"* |
| 11 | *Importance of Science in a Bildung Perspective* | Focus on developing students as persons who can reflect on science as they take part in society. Sample wording belong to this theme (2004/2007/2010): “*[students] can express a knowledge-based opinion on issues and problems with a natural sciences aspect.”* |
| 12 | *Implementation of Teaching* | Requirements for implementation. The theme appears in 2007 and 2010. Sample wording (2010): *”[…] observations should be integrated into teaching and choice of themes should make possible [student] completion of [student activities present in other themes]”.* |
| 13 | *BSC Identity as a Course* | Constitutes the BSC as a subject, which introduces the natural sciences and scientific methods. Sample wording belonging to this theme (2007): *"introduction to natural science (...) through working with the basic elements of natural science with emphasis on the coherences in natural science."* |

Evolutions of themes



Figure 3. The merger of Themes 11 and 13 over three iterations of the BSC curriculum text. Circles represent words in the curricular texts and arrows their connections. Words represented by purple circles belong to Theme 11, while words represented by green circles belong to Theme 13. Words were assigned to themes based on their connections and using the computer algorithm Infomap (see above). Over time, words in the two themes become more connected and end up in 2010 as one theme. To illustrate how this happens, we have translated the words science, subject, and work from Danish, while remaining Danish words were greyed out. Visualisation made with software Gephi (gephi.org).

Figure 3 shows the merger of Themes 11 and 13 as illustrated by the network structure of the two themes. In 2004 and 2007 they appear as two distinct but connected themes: *Importance of Science in a Bildung Perspective* (Theme 11)and  *BSC Identity as a Course* (Theme 13)*.* Notice that there is only one link between the two Themes in 2004 (a green arrow from *science* to *subject*). This is the reason the Infomap algorithm identifies these themes as separate. In 2010, the word *science* is central and connects (among other words) *work* and *subject*. The structure is denser than in 2004 and Infomap identifies the words as one theme. We interpret 2007 as a middle position: there are more connections between words in each theme, but they are still distinct. We have highlighted *science, subject,* and *work*, because these words are highly connected in the network and prevalent the curricular texts. The merger could be seen as a shift in intentions: Instead of working with different science subjects, science is seen as the overarching subject. This may indicate that the intentions for the BSC develop from an agglomeration of different disciplines to a discipline in its own right.

As seen in Table 1, Theme 10 mentions pluridisciplinarity (Jantzch 1972, p. 15-16). The framing of pluridisciplinarity changes over time. This change is mainly visible as a substitution of and later removal of words: From teaching topics being “*preferably pluridisciplinary”* (2004)*,* to being “*normally pluridisciplinary” (2007)* to being *“thematic plurisciplinary topics”* (2010). This can be seen as a move from pluridisciplinarity as a suggestion to becoming the norm to becoming taken for granted.

Theme 12, which first appeared in 2007 gained clearer connections to Practical Work, Hypotheses, Competences to be Learned, and Theme 11+13 in 2010. See Figure 2. The theme contains national instructions to how teaching should be implemented and the connections to Practical Work and Hypotheses provides further indications of this instruction. For example, practical work should be integrated into teaching as opposed to an appendix to teaching. Also, observations should in some cases be used by students to generate hypotheses. The Danish system relies heavily on teacher autonomy (Evans et al. 2018), such instructions may be seen as decreasing that autonomy.

Discussion

This study has potential implications for our understanding of the interplay between curriculum texts, practice, and political trends. For instance, one could ask if the merger between Themes 11 and 13 in 2010 aligns with public discussions about the relationship between Bildung and Science in preceding years. In terms of practice, an investigation of teachers’ perception of the purpose of the BSC aligns well with the merger between Themes 11 and 13; the BSC is often seen as a Bildung course with emphasis on interdisciplinarity (Dolin et al. 2016). However, we emphasise that the type of interdisciplinarity advocated in the BSC curriculums is pluridisciplinarity which does not necessitate that subjects coordinate with respect to a joint problem (Jantsch 1972, p. 15-16).

It is important to emphasise that the final products of our TDNA consisted of all three parts: our thematic network maps, linguistic networks, and an interpretation. A complete picture will include taking all these parts into consideration. For example, thematic maps did not show every grain of detail of clusters and their interconnections. Therefore, it is also interesting to ask, which themes were not shown in the thematic maps. In our case, one theme was consistently present for all years, but was never prevalent enough to show up on the thematic maps. The theme represented a string of words: *inductive* –> *teaching principle* –> *prioritise* –> *autonomous* –> *work processes* (translated from Danish). This string of words was connected to the rest of the network only through its connection with the word *teaching (teaching* and *teaching principle* are different words in Danish*).* Since *teaching* is part of Theme 12, this small cluster is connected to *Implementation of Teaching*. In fact, the initial CDA identified this as a subtheme of Theme 10. However, the theme consistently showed up as a separate theme, weakly connected to the rest of the network. The appearance of Theme 12 in 2007 and 2010 may signify that a discursive practice that specifies in more detail what students should do in teaching has gained ground.

Appropriateness of thematic maps

Just as was the case with group discussions (Bruun et al. 2019) and keywords analysis (Fairclough et al. 2011), we found that using TDNA revealed themes that were not part of the initial analysis. Furthermore, we made connections between these themes (and their development) and other discursive markers, in this case other articles and reports. However, we have not shown that our thematic maps correspond to either the intentions of curriculum authors or explicit interpretations of teachers. We may speculate that curriculum texts are formulated in official bodies through a process that involves both political intentions as well as educational expertise. This process has to the best of our knowledge not been documented.

Instead, in order to gauge the appropriateness of thematic maps with regards to political intentions, future research could further integrate the methodology with critical discourse analysis to compare their development to political debates about the curriculum or investigate further links with survey data. For example, one could look for evidence that the emergence of *Implementation of Teaching* in 2007 was correlated with confusion about how to implement teaching in this new school subject. In connection to teacher interpretations, maps like these have been used to analyse other curriculums (Elmeskov et al. 2015) and, as mentioned, in teacher professional development (Evans & Dolin 2018). To gauge whether the maps in this study capture teacher interpretations or could help bridge the gap between official intentions and current teacher practices, future action research could strive to use these maps in trial teacher professional development.

Conclusion

In this work, we have illustrated how thematic discourse network analysis (TDNA) integrated with critical discourse analysis (CDA) can be used to identify and interpret interconnected themes in three different iterations of a curriculum text. We have also shown how themes may change internally and externally signifying potential differences in political intentions and possible interpretations. Further research may link these potential differences to accounts of political decisions and to teacher implementation.

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