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Students' Insights from Interactive Visualizations Arranged Multimodally in Knowledge Visualizations

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In this study, a visual analytics application is put into practice in Swedish secondary school social science classrooms. The application offers support to analyse vast amounts of data through interactive data visualizations. Previous studies have demonstrated that the visual interactive interface challenges the traditional practice in school, where students usually demonstrate their knowledge by means of written texts. Thus, this study examines what happens if students work with more malleable, adaptable, or fluid modes when attempting to express their conclusions from work with interactive data visualizations. It aims to detect patterns in how knowledge visualizations are produced and arranged multimodally. Inspired by design-based research, the study conducted two classroom interventions followed by video captures. It

employed a socio-material semiotic approach, which enables the study of interactions between both social and material actors. Three patterns emerged when students' insights were translated into knowledge visualizations – exploring, gathering, and inserting. It became obvious how different actors taking part of such a digital multimodal writing activity affect and change every actor/everyone/everything, which in turn transfers, relocalizes, reformulates, and re-presents the communicated message. Knowing how knowledge visualizations are produced might strengthen students' visual abilities when transforming insights multimodally.

Keywords: design-based research, knowledge visualizations, multimodal arrangement, social science classrooms, visual analytics

1. Introduction

In these times of information overload, 'alternative facts', and fake news, it is essential to support students' abilities to consciously choose relevant data, to interpret and analyse, and to communicate information, or more precisely, to represent the insights they may achieve (Nissen & Stenliden, 2020). Today, there are tools to assist students, and others, in such efforts. These applications have been developed within the interdisciplinary research field of visual analytics (VA). Based on information visualization alongside cognitive and perceptual sciences, this research field aims to facilitate analytical reasoning through designing technology that supports the sorting, arranging, and analysing of data (Thomas & Cook, 2005). Hence, VA applications use interactivity and data visualization (often official statistics¹) through colours, forms, maps, diagrams, moving timelines, et cetera (see Figure 1). Tableau, Qlick view, and Statistics eXplorer are examples of such VA applications. They provide an interactive interface that offers various visualizations of official statistics (Lundblad, 2013). Tomaszewski and MacEachren (2012) point out that the features of VA are designed to take advantage of the human visual capacity in structured ways. Hence, the analytical processes are designed to be supported by interaction with visual objects (Andrienko et al., 2011).

¹ According to the UN (2014), official statistics are based on 10 fundamental principles. They should be compiled and made available on an impartial basis by official statistical agencies; they are an indispensable element in the information system of a democratic society; and the statistical agencies should decide according to strictly professional considerations, including scientific principles and professional ethics, on the methods and procedures for the collection, processing, storage, and presentation of statistical data.

However, the main diagram research community has not yet extensively explored the connections between interactive graphs and their interpretation, namely the process of reading interactive maps and graphs (Purchase, 2014; Treagust, Duit, & Fischer, 2017).

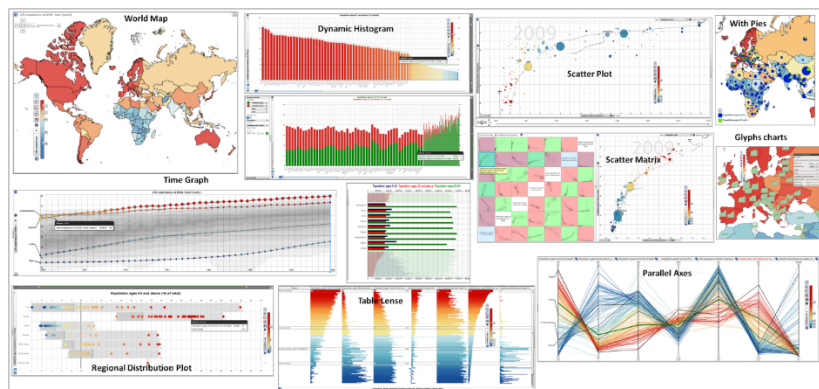


Figure 1. Data visualization – toolkit and interactive features represented by layered choropleth map, composite time-linked histogram, time graph, scatter-plot view, parallel axes plot, etc.

It is important to think further about multimodal opportunities in education for many reasons. One is that empirical evidence shows that such opportunities improve the knowledge-gathering process (Roll & Wylie, 2016; Baldwin, 2015, 2016), but at the same time, students also experience problems concerning ‘the reformation’ of such knowledge outcomes in school (Stenliden, 2014; Åkerfeldt, 2014b; Hashemi, 2019; Sefton-Green, 2021). For example, studies have shown that VA applications clearly support school students in handling visualized, large, and complex data sets but that the tools’ multimodal and interactive opportunities seem to ‘collide’ with schools’ common ways of encouraging students to demonstrate their knowledge (e.g., Stenliden, 2014, 2015). According to Stenliden (2014, 2015), students’ efforts to analyse and reflect upon the visual information provided were characterized by a rather stressful approach because their ambitions were primarily to quickly transform their findings into written text. Usually, the students’ verbally expressed conclusions after interacting with the data visualizations were of a higher quality than those they were able to translate into a written, text-based modality. Accordingly, the option to demonstrate insights drawn from interactive data visualizations is narrowed down for students in school if they are required to produce a written text as ‘proof’ of having achieved knowledge.

Regrettably, this rather ‘static’ mode seems to limit the possibilities for transferring and demonstrating the gained knowledge in ways that are beneficial to the students. Moreover, even though students have the option to choose other multimodal means and methods in schools, they often choose a written text mode anyway in order to complete their assignments and present evidence of insights gained in the classroom (Stenliden, 2018). Teachers seldom actively encourage students to choose other modes during this part of the knowledge-acquisition process (Sefton-Green, 2021; Bodén & Stenliden, 2019; Åkerfeldt, 2014a, 2014b).

However, since students are evidently capable of interpreting, analysing, and gaining insight into vast amounts of data by interacting with multimodal VA applications, methods for how their insights can be reformulated and represented in an ‘appropriate’ mode must also be developed. This is in line with many researchers (e.g., Baldwin, 2015; 2016; Bearne, 2009; Cope & Kalantzis, 2000; Purdy, 2014), who emphasize that when working with multimodal technologies in schools, it is important not only to thoroughly develop students’ ability to understand what is seen, interpret what is experienced, analyse what they have been exposed to, and evaluate and draw conclusions but also to develop their methods for representing this ‘multimodal’ knowledge formation.

Therefore, inspired by the field of knowledge visualization (KV), this study aims to examine what happens if students work with more malleable, adaptable, or fluid modes when attempting to express their conclusions from work with interactive data visualizations. KV deals with how to externalize ideas, facilitate comprehension, and communicate information or knowledge (Burkhard, 2005; Bertschi et al., 2011; Tversky & Suwa, 2009). It is about creating and applying visuals such as sketches, images, arrows, and lines with the purpose of constructing and communicating meaning (Crawford, 2012; Tversky & Suwa, 2009). According to Eppler (2013), KV is a process that may help to both create and transfer knowledge, a process aiming to support the ‘sender’ (in this case a student) in enabling the ‘receiver’ (here the teacher) to understand and represent the knowledge gained during activities in a classroom. Hence, through an intervention in two secondary school social science classrooms that employs a specific VA, Statistics eXplorer, the students in this study are explicitly encouraged by their teachers to create KVs to present their

insights. The students are supported by various modes, such as a combination of visualizations and texts.

This study examines how students' insights, gained from analysing official world statistics as displayed by Statistic eXplorer's interactive data visualizations, are translated into multimodal knowledge visualizations. By following the interactions between students and the interactive data visualizations, the study aims to detect patterns in how the KVs are produced and arranged multimodally.

The research questions are as follows:

- What characterizes the translation processes in the production of knowledge visualizations in social science classrooms?
- What characterizes the mobilization of such multimodal arrangements?

2. Previous research

The huge diversity of digital expression forms, now appearing across all sorts of media, raise questions about what communication might mean. Traditional methods for communicating possible insights to others are being contested, and understanding the conceptual practices of how a 'message' might be transferred across media or mutate into various kinds of crossbred genres becomes increasingly important for schools (Sefton-Green, 2021).

2.1 Communicative practices

Thinking about practices of communication and people is often an enterprise located within human brains, but Pennycook (2017) highlights that sensory (bodily, visual, or oral) experiences cannot be separated from materiality, spatiality, artefacts, entities, et cetera. Kress and van Leeuwen (2006) address how communication is affected by digital technology, where semiotic principles are used in and across modes. Wyatt-Smith and Kimber (2010) discuss how the 'new' technologies make it possible to create and share information in more dynamic and multimodal manners. Moreover, Jewitt (2014a, 2014b) points out that, when taking a multimodal approach, practices of

communication apply to the meaning potential of all modes. Consequently, when students (and others) communicate insights using digital technology, many different factors come into play as a complex act of *resemiotization* (Iedema, 2003) or, as Pennycook (2017) puts it, a *relocalization* emerges.

At the same time, because of the intensified use of various digital means and modes, for example, as text and visual information on screens, traditional ideas about reading and writing are becoming contested (Bearne, 2009). The challenge concerns not just how to describe writing/producing text in digital ways but also how to explore the ways in which other forms of narrative, exposition, argument, and so forth take place through digital media and where the boundaries between textual forms (text, image, audio, etc.) become blurred by digital technologies (Sefton-Green, 2021). Kress (2010) explains that digital resources make the shift between various modes, that is, *transduction*, easier. When information conveyed in one mode shifts to a different mode, it is also considered to be *synaesthesia* (Cope & Kalantzis, 2010). A third concept for this transfer across multiple modes is *semiotic remediation* (Shipka, 2011). In this study, we apply the term *translation* (Callon, 1986; Latour, 1987) to denote the process of resemiotization. Translation is the transformation process of different actors taking part in, for example, a digital multimodal writing activity – a process of interaction that affects and changes every actor/everyone/everything.

2.2 Knowledge Visualization

According to Meyer (2009), traditional methods for communicating possible insights to others through text and numbers have become more difficult, as information has both increased in volume and become more complex. Correspondingly, Bertschi et al. (2011) highlight that the possible limitations of expressing knowledge only in written text can be overcome by applying the values of KV. They argue that organizing information and mapping concepts graphically, using both text and visuals, helps to outline the principal ideas and demonstrate how concepts relate to each other. They point out that structuring text and visuals in a meaningful way facilitates the process of communicating insights to others. This is in line with Meyer (2009), who highlights visuals as a means for creating and transferring complex information or knowledge. Images support the transformation and make the process more efficient. Moreover, Meyer (2009) discusses the importance of access to visualization software and the significance of providing guidance to users

regarding visualization methods. However, as both Meyer (2009) and Bertschi et al. (2011) explain, KV is not necessarily just a process for communicating with others; it might also be used to aid in remembering what you have learned for yourself. In educational practices, both these kinds of processes are common. Hence, several studies argue that KV is a crucial stage in the knowledge acquisition process (Eppler, 2013; Sabol et al., 2012; Seifert, Sabol, Kienreich, Lex, & Granitzer, 2014; Segel & Heer, 2010). Tversky and Suwa (2009) argue that creating visuals helps to externalize ideas, making them more permanent and facilitating comprehension and inference. The visuals improve the processes through which ‘things’ (knowledge) can be identified, organized, shared, discussed, applied, and generally managed (Bertschi et al., 2011). The visuals are artefacts that allow community participation and checks for completeness and consistency. However, depending on the situation, certain qualities of the visuals may affect the results (Eppler, 2011). In brief, by interpreting information – by understanding, developing, organizing, and designing information – the communication and expression of knowledge become a non-linear process (Tergan et al., 2006; Crawford, 2012).

2.3 Visual arrangements

According to Eppler and Burkhard (2007), if we wish to communicate convincingly when supported by visuals, we must present the assembled and displayed information, knowledge, opinions, et cetera all at once to the receiver of the message. The ‘things’ have to be ‘*presentable, readable, and combinable*’ in a logical manner (Latour, 1990, emphasis in original), for example, by giving an overview of details or presenting a top-to-bottom process in a problem analysis (Tufte, 1997). In this scenario, visual discovery is understood as the pursuit of novel insights that take on a different form because they are generated out of the analysis and then visualized via individual or collective views (Ryan, 2016). When this happens in reasonable ways, when ‘things’ are linked in one of numerous forms of approach, they may facilitate readable and acceptable discoveries emerging from shared insights (Suthers, 2001). Bezemer and Kress (2016) highlight that design is prospective, which means that new meanings are always created in design processes like these.

Kress and van Leeuwen (2006, p. 177) propose that such composition relates the representational and interactive meanings of an image to each other through three interrelated aspects: *information value* created by the placement of the elements, for example, the various ‘zones’ of the image

(left/right, top/bottom, centre/margin); the *salience of elements* which attract the viewer's attention as positioned in the foreground or background, their relative size, contrasts in tonal value or colour, differences in sharpness, and so forth; and the presence or absence of *framing* devices realized by dividing lines that connect or disconnect elements of the image, signifying that two or more elements belong or do not belong together in some sense. They argue that even when we express what seem to be the same meanings in either image form or writing or speech, they will be realized differently. How something is expressed – verbally, bodily, or visually – makes a difference (Kress & van Leeuwen, 2006).

2.4 Multimodal productions in schools

Whereas multimodality in schools was previously connected mainly to students' receptive skills, there now appears to be a shift towards multimodal student productions (Elf at el., 2018). Studies by Felten (2008), Elkins (2008), and Bresciani and Eppler (2015) show that it is especially important to promote students' ability to assemble meaning, not only from traditional text but also by interpreting or reading images, and their ability to represent and produce visual messages to use in communication with others. Brownell (2020) reveals how young students, throughout a remediation process, learned to develop a facility for using multiple communicational tools and practices. As the students nimbly shifted communicative modes, languages, and cultural practices, they cultivated a diverse skillset of communicative practices. Additionally, as the students experimented with an array of materials, they began to understand the rhetorical affordances and constraints of each mode in relation to their intended purpose. Comber (2016) explains that children discover what their symbolic resources can do: '[they] amuse, question, persuade, convey ideas, play, record ongoing events, and on and on' (p. 119).

On the other hand, there are studies which report on how a multimodal approach is difficult to enact in the classroom due to issues related to school traditions, teachers' competence, the challenges of power relations in the classroom, and even resistance from students (Aagard & Silseth, 2017; Cederlund & Sofkova Hashemi, 2018; Godhe, 2014). Students' motivation when they are creating hybrid forms may stem from different disciplinary ambitions for example, the desire to make a video as opposed to writing an essay. Brownell (2020) explains that teachers from

numerous encounters know how confusing such moments can be. This is especially because, when they include different or unusual resources, the expectations of such experiences in the classroom can often be as unclear and deflating as they are inspiring and affirming. Furthermore, several studies highlight how students who are able to produce multimodal productions in turn challenge teachers' traditional assessment practices (e.g., Baldwin, 2016; Magnusson & Godhe, 2019). Indeed, the language of genre and discipline is central to the ways in which teachers might understand (1) development/progression, (2) complexity, and (3) aesthetics. All three concerns dominate both teaching and learning, as well as the circulation and assessment of any student-made productions or performances (Sefton-Green, 2021).

However, there has been little empirical research on the specific ways in which understanding the conceptual practices of translation/reformulation/representation might transfer across media and develop iteratively when moving from one kind of text to another, or from one form to another, or even how it might mutate into various kinds of hybridized genres (Sefton-Green, 2021). Altogether, a student's process of achieving visual discoveries/insights with a VA, with the ambition to communicate or express these in a multimodal manner, leads to a renegotiation of the communicative practices in the classroom. Therefore, when studying such processes, it is essential to take a theoretical approach that enables the study of the process of interactions between both the technology and the student.

3. Theoretical perspective

To explore how students' insights stemming from visual analyses are transformed into multimodal presentations, this study uses a socio-material semiotic approach because it enables the study of interactions between both social and material actors. This is a theoretical stance within the tradition of Actor-Network Theory (Latour, 1993, 2005; Law, 2007; Fenwick & Edwards, 2010). Such a socio-material semiotic approach entails that the students, the interactive visualizations using maps, colours, bubbles in a scatterplot, etc., the cursor, presentation programmes, the teachers, and several other aspects are all viewed as heterogeneous actors. This enables the study of how social and material actors interact and perform *together*, rather than the focus on humans' interaction *with* artefacts or their *use* of the tools (Latour, 2005). Thus, this approach emphasizes that the social and material actors are to be dealt with as equals – with material

heterogeneity (Callon, 1986; Callon, Law, & Rip, 1986). As the social and material actors interact, networks are produced. The more frequently the actors successfully interact, the stronger the network becomes (Law & Hassard, 1999). When they interact, they also transform (Callon, 1986; Law, 2007). When this occurs, the actors in the network affect and change each other, forming links (Fenwick & Edwards, 2012). This is defined by the concept of *translation* (Callon, 1986; Latour, 1987). Translation is a process that is both insecure and precarious; sometimes the interactions are complete and strengthen the relations among actors, and other times they might fail and weaken those relations (Callon, 1986; Law & Hassard, 1999). Callon (1986) asserts that it is possible to discern four ‘moments’ in the translation process – problematization, intersement, enrolment, and mobilization – when following how the interactions in a network, the relationships, are constructed. In the *problematization* moment, efforts are made to identify actors and their roles, define the nature of the problem, and establish links and alliances. The actors enlisted in this problematization will either refuse interaction or become integrated in the moment of *intersement*. According to Callon (1986), it is the actions that form and adjust the actors, attempting to impose and stabilize what they are and how they may be locked into place. This is a crucial moment when the relations are put to the test; the outcome will affect the translation process. An actor can interest another one by placing devices between it and others – cutting their links – thereby consolidating its own relations. Hence, competing associations are interrupted when constructing a powerful system of alliances. If successful, the intersement supports actors to become *enrolled*, which is the next moment in the translation process. This is when multilateral negotiations take place concerning what the actors are, how the various roles are defined and interrelated, and whether these are accepted by the actors. Previously uncertain questions, from earlier in the translation process, are now transformed into more certain statements of actors/actions within the network. However, as Callon (1986) puts it, success is not guaranteed because ‘enemy forces’ attempt to contest or prevent the alliances. However, if actors are willing – some after long negotiations, others without resisting at all – enrolment is achieved. Finally, the *mobilization* moment occurs when, through a chain of intermediaries and equivalences, actors designate a spokesperson who is able and willing to represent and speak in the name of others. At first, the actors are dispersed, but then they become reassembled and, as the spokesperson speaks in their names, they are rendered mobile

(Callon, 1986; Law, 1987). The four moments can overlap and do not necessarily have to occur in the order given above.

The study uses this theoretical frame to focus the analyses on interactions within the networks, namely the translations between the different actors – for example, the students, the teacher, and the features in the VA.

4. Method

This study is inspired by design-based research (DBR), a procedure that was developed by and for researchers and educators working together. It provides a bridge between educational practice and theoretical research and is intended to improve educational practices (Anderson & Shattuck, 2012; Easterday, Rees Lewis, & Gerber, 2016). Phases of DBR include forming a close collaboration; focusing on the design and testing of a significant intervention; using mixed methods and multiple iterations; and generating design principles and theory (Anderson & Shattuck, 2012). In short, it offers a method whereby teachers and researchers can design and re-design the research process in an iterative cycle where the outcome of one phase affects how the next one is designed and implemented. Thus, a close collaboration between teachers and researchers was set up, and the teacher-researcher team (TRT) jointly designed and conducted lesson plans that were realized through two classroom interventions. This study encompasses the second intervention, which aimed to further enhance the teaching activities. Specific ways of using the VA and KVs, instructions, assignments, and assessment methods were developed in new lesson plans.

4.1 Statistics Explorer – a VA application

As mentioned above, the studied intervention employed the VA application Statistics eXplorer (Figure 2). The application visualizes official statistics from the World Bank in the form of interactive maps, graphs as scatterplots, and bar charts, as well as moving timelines. Statistics eXplorer offers storytelling methods that can support the creation of interactive visualizations. The storytelling process of transforming massive amounts of statistical information about the world into an understandable story makes it possible to customize teaching materials. By choosing indicators relevant to the social science theme ‘Trade and Consumption’, the TRT produced one interactive data visualization – a Vislet (a wordplay on booklet). The Vislet included visualizations

about trade: General Net Income (GNI), imports, exports, and consumption in the world. It also contained, in a textbox, written assignments set by the teachers to guide the students in handling the technology and processing the content. By interacting with the Vislet's content, the students explored global trade patterns by interpreting and analysing the statistical data, gaining insights, and drawing conclusions about causes and consequences. Then their assignment was to transform their insights into multimodal KVs. The teachers emphasized that these KVs were to be mainly visual presentations and encouraged the students to refrain from written text except where it was unavoidable.

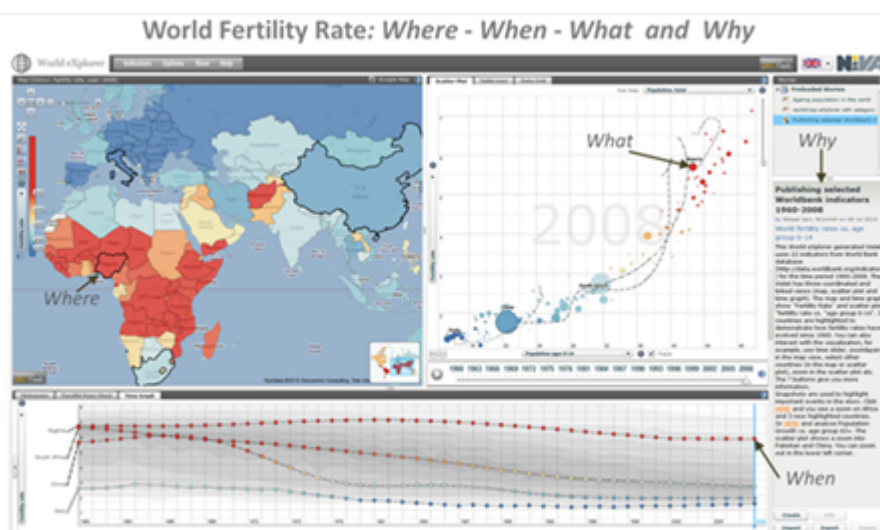


Figure 2. Visual features and functions of the Statistic eXplorer application: a map, a scatterplot, a chart, and a textbox with explanations and student assignments (image source: Mikael Jern, Linköping University).

4.2 Classroom context

Introducing the social science theme ‘Trade and Consumption’, the teachers commenced by guiding students through the topic instruction, available in a digital presentation (DP) on the school’s learning platform. This contains goals, methods, various assignments, and instructions for how to produce the KV (using DP) together with instructions for the assessment (the presentation of the KV) at the end of the theme period. The topic instruction, together with an assessment

matrix, were accessible to the students at all times. Having provided this information, the teachers focused on demonstrating the VA application. They explained and demonstrated the visual features – such as the map, the scatterplot, the assignment textbox (with several assignments to support the students in gaining insights from the Vislet), and the timeline – how they are connected (dynamically linked), how to ‘read’ the x- and y-axes, and so on. The teachers also pointed out the significance of visual properties such as colour, highlighting, and size of bubbles.. They also demonstrated interactive functions, which are necessary when navigating and interacting with the visualizations, such as the interactive timeline, indicators (demonstrating statistical information about, for example, population, exports, and imports), various zooming buttons, the way to reset the preadjusted interface, and links within the Vislet and to other web pages. Regularly during the lessons, the teachers assembled the class for joint discussions about what the students had found in the Vislet or something that the teachers wanted to highlight. They also led instruction sessions about the aim, method, and assessment matrix from the topic instruction and technical functions of the Vislet. From the start, they encouraged students to note their insights when interpreting and analysing the information in the Vislet; for example, they suggested collecting screenshots, reasonings, images, or short notes that the students could use later in their KVs. The students each had their own computer and mostly worked on their own, but they were encouraged to help each other. On their screens, several documents were opened in addition to the Vislet, such as a text document, the presentation of the topic information, the GP, and webpages where the students could search for supplementary information.

4.3 Data production and analysis

During the course of twelve lessons in two eighth grade social science classes, two kinds of video capture were made, one using a wide-angle camera and one using the zoomed-in mode of the computer. The wide-angle camera was placed at the back of the classroom, recording the activities of the whole lessons, and altogether recorded 20 hours of footage. This allowed us to both gain an overview of a large part of the classroom and focus on the actions that occurred at the front of the classroom. The teachers were usually positioned at the front when they introduced the assignments, gave instructions, and led discussions. The actions on the teachers’ screens were projected onto the white board, also positioned at the front and thus visible to all students. The interactions between the VA application and the students were captured by webcam recordings, altogether 61.5

hours, using a software package that utilizes the computer's webcam and microphone to record the students' faces as well as their movements and actions on the computer screen (TechSmith, 2010). The students' faces, voices, and gestures as well as their activities on the screens were thus recorded in a zoomed-in mode. The recordings enabled us to capture the interactions between the VA application (the interface on the screen), the students, and the teachers. Field notes were also taken.

The process of identifying, comprehending, and amplifying patterns of interaction (socio-material relations) in the data was guided by 'method assemblages' (Law, 2004). The field notes, focus-group interviews, and two types of recordings from the two classes (six lessons per class) were viewed and read by one researcher. The same researcher was present during all the lessons, made the field notes, and conducted the interviews. Another researcher participated in half of the lessons. The third researcher viewed all the wide-angle recordings. The parts of the recordings that were identified as crucial were transcribed (Heath, Hindmarsh, & Luff, 2010). In the analysis process that we used, it was not enough to observe only the dominant work practices; instead, we needed to grasp the complexities and the unexpected in an attempt to understand what was and was not happening in the classrooms. Accordingly, in this process, we used the idea of 'moment analysis' to capture seemingly spur-of-the-moment actions that were highly significant to the actors and their subsequent interactions; the causes of such actions; and the consequences of such moments, including the reactions of other actors (Wei, 2011). Since pre-determined coding or categories were not used, the analytical attention was instead an open-ended process of sense-making, as described by Massumi (2002), during which perception, cognition, and affect were interlinked. This entailed a tentative unveiling of the data. This partial unveiling is an enactment of crafting and can assist in detecting both what is discovered and what might be overlooked. During this analytical process, we used the concepts of interaction, actor, network, and translation. This approach enabled us to recognize essential patterns in the students' production of KVs as well as how they are multimodally arranged.

5. Production and mobilizing of multimodal Knowledge Visualizations

In this section, we analyse events from the classrooms and illustrate characteristics of how insights from the interactive visualizations are transformed by translation processes into multimodal KVs and how the mobilization of the ‘completed’ multimodal presentations are outlined.

5.1 Characteristics of the translation processes

This study revealed, three distinct patterns: exploring, gathering, and inserting.

5.2 Exploring

The event ‘Wow! Cool!’ illustrates that exploration constitutes the initial pattern of translating insights into multimodal KVs. This is the first lesson with the VA for Maria and Sara, two of the students.

The event ‘Wow! Cool!’:

Maria alternates between looking at her screen, the teacher, the classroom smartboard, and Sara’s screen, her hand holding the mouse. The cursor on her screen starts to move. Maria’s gaze now focuses intensely on her own screen. Immediately, the cursor moves to the map and circulates there for a while. Then the cursor moves towards the visible zoom button and stops for a moment. Then it continues to the scatterplot, slowly getting closer to a big blue bubble. As it stops exactly on the bubble (revealing the tooltip), a black-and-white textbox unfolds, displaying the name of the country and continent (India, Asia), the indicators (GNI, exports, and population), and their value. Maria’s gaze focuses on the blue bubble and the textbox (Figure 3).

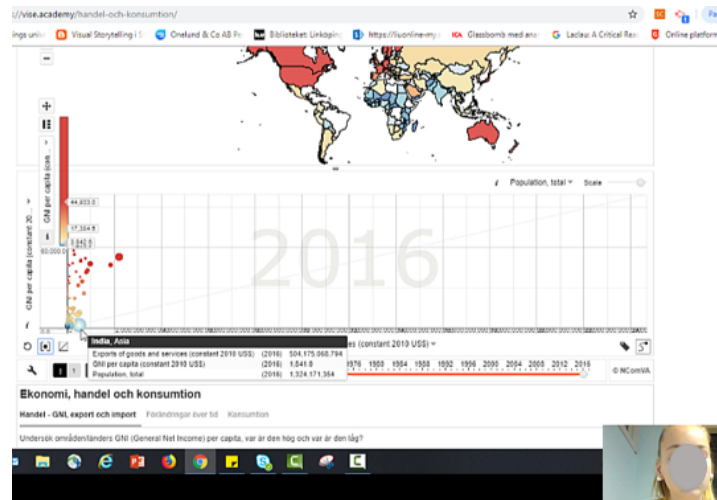


Figure 3. The preadjusted interface of the Vislet, demonstrating actors such as the map, the scatterplot, indicator lists, timeline, zooming buttons, assignment textbox, etc.

Shortly afterwards, the teacher demonstrates the indicator lists (placed on the x and y axes) and informs the students about the indicators displayed on the map and scatterplot. The cursor simultaneously moves to the indicator list. The teacher continues to talk, now about the assignment textbox at the interface, and the cursor in Maria's interface quickly moves to that area. The girls start to discuss how to solve the first assignment, finding countries with high GNI. Maria leans towards Sara's screen.

- What did you do to zoom in that much? Maria asks.
- You must do a square around everything, Sara responds.
- Ahaaa, Maria says.

The cursor moves to the upper left corner of the scatterplot diagram where the bubbles are located. There it clicks, holds, and drags until a thin square frames all the countries' bubbles. As the marked area (the square) is 'released', the zooming function spreads out all the bubbles over a larger part of the scatterplot, which makes them more easily distinguishable (Figure 4).

- Wow! Maria calls out.
- Cool! Sara comments.

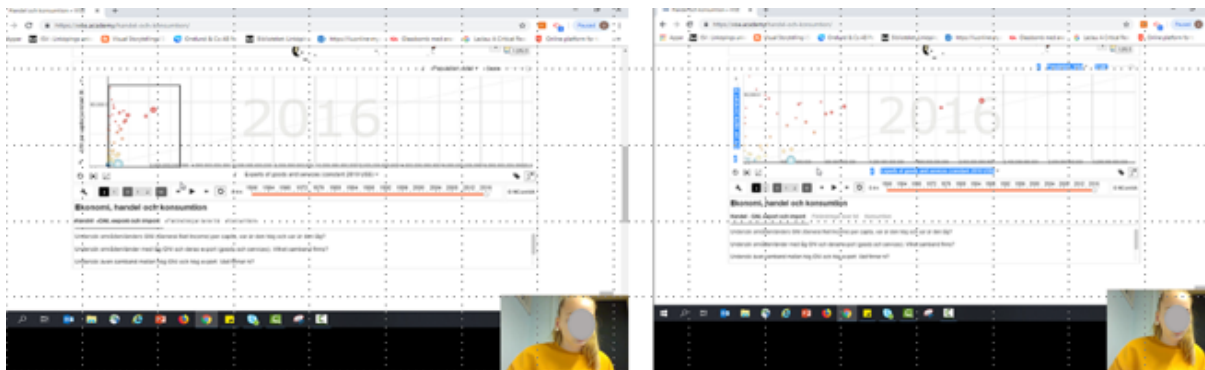


Figure 4. Screenshots from the scatterplot in Statistical eXplorer, demonstrating the zooming by Maria and the cursor.

The interactions within this event reveal how exploration takes place through movements and connections among the socio-material actors. At first, the actors seem to be dispersed, but they soon start to interact in an emerging network. For example, we see how the cursor moves, tentatively, to different visuals within the interface of the Vislet, like the map, the scatterplot, and the textbox containing the assignment text. Another example of movement is Maria's gaze, which is alternately directed towards the teacher, the smartboard, and her own and Sara's screens. These interactions demonstrate how the actors are together trying to figure out how this interface works. These exploratory interactions can be viewed as problematization, the first moment of translation; that is, by means of these movement interactions, efforts are being made to identify actors and their roles and to define the nature of the assignment. Furthermore, this moment of problematization involves interactions with a slightly changing character as the actors no longer just move around randomly but start to create connections more actively. This occurs when Sara, Maria, the cursor, and the visuals in the interface connect more firmly as the cursor clicks, holds, drags, and frames the bubbles with a thin square and then spreads out all the bubbles, followed by the students' outbursts of 'wow' and 'cool' (Figure 4). By means of these connections, the interface also changes, and through these interactions, the role of each actor becomes clearer – for example, demonstrating information multimodally, finding out what the various visuals do, and what happens when something is hovered over or clicked upon (i.e., the tooltip and zooming functions). As Maria and Sara successfully connect with and thereby understand some of the features of the

VA, we can see how the roles, links, and alliances between the actors are being established. Thus, through movements and connections as part of the exploratory pattern, the actors support each other in handling the technology as well as working with the assignments.

However, challenges may also appear when the actors are unable to connect, and the emerging network risks becoming weakened. As an example, this occurs, albeit momentarily, when something unexpected happens shortly after the successful zooming in Figure 3.

The cursor moves around in the scatterplot area and suddenly a new thin square appears, but this time, it is placed outside the scatterplot, not where the bubbles are. The cursor drags away one of the blue-highlighted indicator lists for a second, but then it goes back to its original place.

- Oh, no! I don't know what I did! Ooh! Maria exclaims.

At once, the cursor clicks outside the area, and both the square and the blue highlighting disappear. Maria looks calmly at the screen again, and the cursor keeps on moving around in the scatterplot.

Here, the sudden and unexpected appearance of a square outside the scatterplot and the indicator list seemingly being dragged away challenge the network. If the actors had failed to reconnect, the exploration could have stopped there. Nonetheless, the network is not weakened this time because Maria and the cursor interact so that both the square and the blue highlighting disappear and the interface changes back to its initial position. Challenges of this kind sometimes lead to dissolving networks, as students are unable to connect to the VA and the exploratory interactions stop.

In our interpretation, manifested by the interactions displayed in this event, a network involving a multitude of actors has evolved. At the same time, exploration appears as one traceable pattern in which movement and connection appear as the shapes of the interactions.

5.3 Gathering

Gathering constitutes a second discernible pattern, illustrated in the event below in which the teacher Carrie, the students Maria and Sara, and other students continue to work with the VA.

The event ‘Swift gatherings’:

Maria’s hand is placed on the mouse, and the cursor moves around the map and the scatterplot. It stops first at Norway (the highest GNI) and then at Burundi (the lowest GNI) and tooltips the bubbles.

- Ok, so Norway, Sara says.
- Norway is the one with the highest, Maria says.
- And this is the lowest, she continues.

Simultaneously, the cursor tooltips the lowest blue bubble, and a black-and-white textbox with facts about Burundi folds out. Then the cursor clicks on the text document. It opens, and Maria writes her insights about Norway and Burundi, her fingers moving swiftly across the keys on the computer’s keyboard. Shortly afterwards, Carrie assembles the class for a brief discussion, and at one point, she states that there does not have to be a correlation between low GNI and low exports. This statement is instantly written down in the text document. During the course of two lessons, the amount of written text increases. The actors then quickly switch back and forth between the open pages on the screen. Carrie frequently reminds the students of the importance of gathering screenshots of their insights. When about one page of written text has been produced, at the end of the second lesson, a screenshot of the map in the Vislet is inserted between the paragraphs (Figure 5).

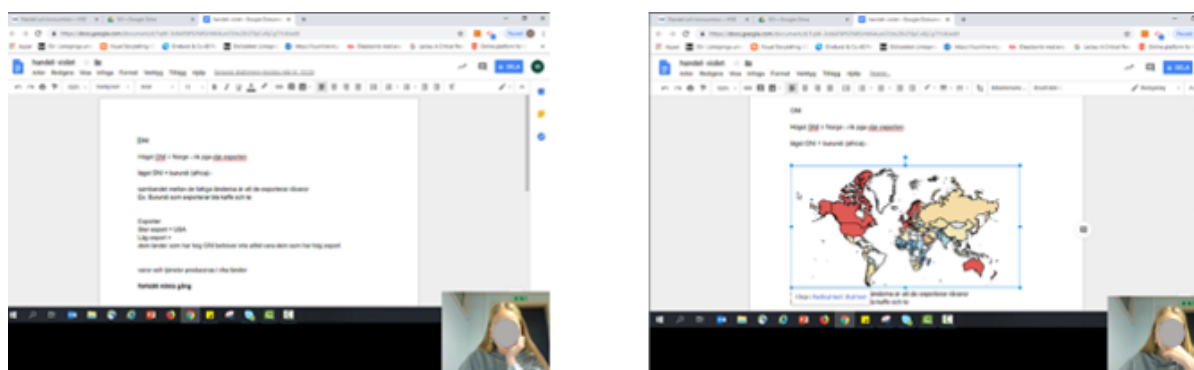


Figure 5. At first, only text is produced in a text document. Later, as shown on the right, screenshots are added to the text.

The interactions between the actors reveal how the network now essentially orients towards discovering how to translate the insights drawn from the VA in a KV; hence, a gathering of insights commences through selecting and storing insights. The rather trouble-free interactions between the students and several other actors in the VA – for example, the links between Maria, Sara, the cursor, the scatterplot, and the zooming functions – become stronger as they now easily, by mutual actions, engage in zooming in on Norway and Burundi. Consequently, Maria's and Sara's interest become evident when they select these countries' GNI to become part of the KV. This occurs when the cursor clicks on the text document, and Maria uses written text to note her insights about the two countries.

Another form of selection occurs when the teacher's statement about GNI and exports – through the interactions between the teacher, Maria, and the keys on the computer keyboard – is written into the text document. The selected insights, both visuals from the VA and verbal utterances by the teacher, are thus transformed into written text. In this way, the insights are accumulated and stored. Initially, the semiotic mode of written text is most frequently utilized, and not until the actors have stored a substantial amount of written text do interactions commence with the screenshot tool and the storing of visuals. These gathering interactions demonstrate a shift: first, the students apply text as a common mode, but then they turn to the option of applying a visual mode. They also demonstrate how the insights are being formed and adjusted in different ways by these modes. It seems like the students' mental model of how insights may be translated from one

mode to another changes. They realize that a visual mode appears to be useful as well. The continuing selecting and storing efforts stabilize what the actors are and how they may become locked into place.

However, it is also evident that that some visual actors (e.g., the map or the scatter plot) may interest the students so strongly that links with other visuals or text (i.e., in the textbox) might sometimes be weakened or interrupted. Therefore, the students might end up with a lot of gathered visuals from one area in the VA, whereas other visuals become rather invisible for them. Hence, the students might not choose the most relevant information.

5.4 Inserting

The third pattern – insertion – is first exemplified in an event from the third lesson in one of the classes. Then, another event follows and creates an elaborate account of the pattern.

The event ‘General patterns’:

Maria’s gaze focuses on the text document, and the cursor copies written text and screenshots and inserts them into slides in the DP. As this takes place, the written text is usually transformed into headlines and bullet lists (Figure 6). On the interface, Maria’s gaze and the cursor move quickly between the open folders (the Vislet, a webpage, the DP, and the text document). Visuals and text are combined in different ways and their disposition and size are frequently changed. Further interactions occur between features in the DP, Maria, and the cursor, when designing the layout and animations or altering the order of the slides. Sometimes the interactions stop, and Maria says that she does not know what to do. Then either the cursor clicks on the folder of the topic instruction, her gaze focuses there, and she talks with Sara or Carrie about how to proceed or sometimes Maria’s gaze focuses on some visualization on the interface, the cursor clicks there, and the interactions continue. Now and then, the students talk together and demonstrate their DPs to each other, and some of them also share their documents digitally. In one of Carrie’s teacher-led instruction sessions, she demonstrates ways to *reinforce* the insights by adding other visuals, such as coloured

frames, underlining, arrows, etc. Shortly afterwards, three black arrows highlight the red areas with high GNI in Maria's DP (Figure 6).



Figure 6. Screenshot from a slide of the DP, written text in a headline and a bullet list, a screenshot of the map visualizing GNI, and black arrows highlighting areas in the visualization.

As the production of a KV continues with the insertion of insights, several new actors (such as the DP and its functions) are integrated in the network. This pattern correlates with enrolment, the third moment of translation, whereby actions that have earlier been somewhat uncertain are now performed with increased certainty. This can be exemplified by the multilateral interactions in this event when multiple actors jointly focus on how to insert and arrange the insights into multimodal KVs. For instance, the cursor quickly moves between the open folders, visuals and text are copied, and coordinated in different playful ways (e.g., experimenting with size and disposition). Furthermore, interactions involving arrangement also occur between the functions in the DP, Maria, and the cursor when designing the layout, applying animations of the slides, and altering the order of the slides. Following these arrangement interactions, improvement becomes visible. Another example of how insertion occurs with visuals is demonstrated in the next event, when the student Mike and the drawing functions in the screenshot tool interact.

The event ‘We can draw and everything’:

Mike's gaze is firmly fixed on the screen, and the cursor moves across a screenshot taken earlier. Suddenly, its shape changes from an arrow into a pencil. As it clicks, holds, and moves around in the screenshot, it draws a red line.

- But... we can draw and everything! Mike says.

The cursor moves around on the screen, stopping at different icons on the menu list of the screenshot tool. It starts to draw asymmetrical red lines and arrows as well as writing text on the screenshot.

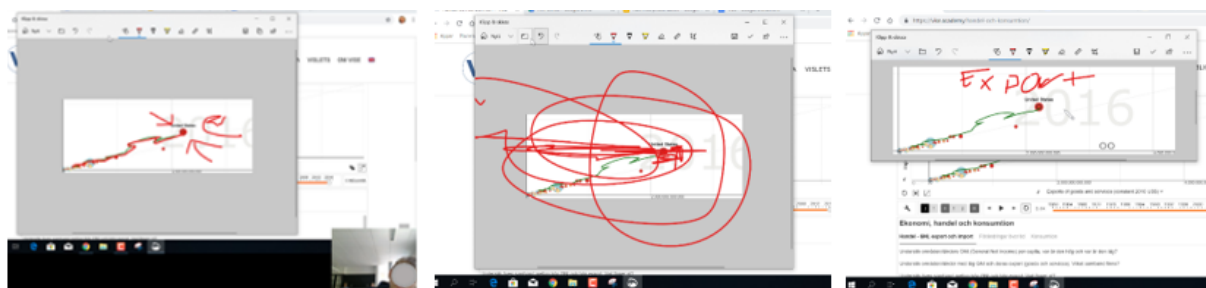


Figure 7. Different kinds of drawings created by interactions between Mike's gaze, the cursor, and the screenshot tool with its drawing functions.

After a while, the cursor clicks on the eraser icon and all drawings are erased. The screenshot is then copied and inserted into the DP. Later on, when the DP is completed, this slide contains reinforcers of a more restrained kind – a green line showing development over the years and red-coloured frames with white text clarifying the indicators Imports and Exports on the x- and y-axes (Figure 8).



Figure 8. The completed slide in the DP, with the reinforcers of red-coloured frames with white text.

Mike, the cursor, and the drawing functions interact several times to draw the red lines, arrows, and red text (visuals as reinforcers), demonstrating a visual playfulness (Figure 7). The arranging, and rearranging, improves the screenshot; when the screenshot is inserted into the DP (Figure 8), it becomes an example of how interactions in the insertion pattern support actors in developing and improving their visual abilities. These interactions are examples of multilateral negotiations between all the actors by means of which they interrelate and coordinate their roles, accepting what the other actors are, thereby becoming enrolled in the network.

Nevertheless, the strength of the network's relations is tested by 'enemy forces' of different kinds. For example, in the event 'General Patterns', this is noticeable when Maria says that she does not know what to do and all interactions stop for a while. However, then the actors jointly find solutions and overcome the challenge when, for example, the cursor clicks on the topic instruction and other visuals or when Maria focuses her gaze or talks to others, and all of this leads to new interactions that once again strengthen the network and support the actors to continue.

So far, the production of KVs has been composed of patterns of exploring, gathering, and inserting insights into a KV. The translation process reveals that the network consists of multiple actors, involved in multiple interactions, and that they identify, form, and adjust to each other. Through multiple negotiations, they also establish links and coordinate their roles, manage challenges, and develop from somewhat tentative to more certain actions. As a result, through the translation processes of problematization, interessement, and enrolment, the insights are transformed into the KVs. It has become obvious how different actors taking part of such a digital multimodal writing activity affect and change every actor/everyone/everything, which in turn transfers, relocalizes, reformulates, and re-presents the communicated message. The KVs – the arrangement of the message – will be analysed in the next section.

5.5 Mobilization of multimodal knowledge visualizations

The students' multimodal arrangements (the KVs) are definitely information rich and are characterized by visuals as carriers of information, visuals as reinforces, and written text as a semiotic mode. Each of these will be exemplified by illustrative slides from the empirical data.

5.6 Visuals as carriers of information

The KVs are arranged in such ways that the visuals are carriers of certain information and contribute to communication in a visually readable manner. The fact-based information that is relevant when completing the assignments is composed in logical ways that support the students in their efforts to transfer their insights and visualize their message. The slide below (Figure 9) illustrates such an arrangement.

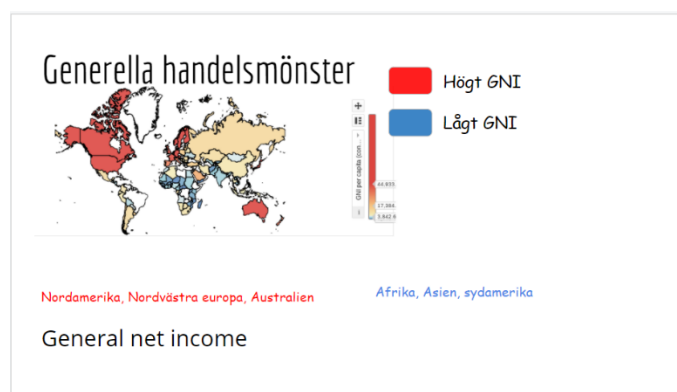


Figure 9. One slide in a KV where the map demonstrates countries' General Net Income.

These visuals carry information about GNI in different ways. By showing all the countries in the world, the slide provides an overall picture of general GNI patterns. The information is displayed by means of the coloured countries on the map. As shown by the key in the middle of the slide, the red colour means high GNI, and blue means low GNI. The key guides the 'readers' (i.e., students) in how to interpret the visual. When the students' gazes connect with this type of visual, they are able to gain insights into, for example, which countries have high or low GNI and the countries in between. Additionally, the map illuminates general patterns, such as Africa and parts of Asia being areas with low GNI and North America, Western Europe, and Australia being areas with high GNI. The visual also carries specific information about outliers, such as Saudi Arabia, which is orange in an area where other countries are blue. In Figure 9, the student reinforced this illustration from the VA with coloured text, red for continents with high GNI and blue for low.

When analysing the visuals as carriers of information, we also found that this representation can at times be characterized as difficult to comprehend. This is the case when parts of the information are obscured, for example, when a zooming action has been performed so that just a few of the bubbles or countries are visible and the opportunity for comparison is missing. It may also be difficult to understand a representation when it partly lacks information (e.g., what indicators the visual is displaying) or when it is blurry. What happens then is that the overall picture is missing (Figure 10).

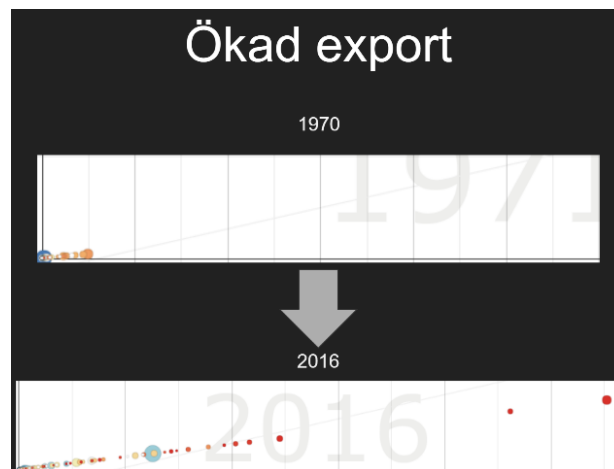


Figure 10. One slide where visuals from the scatterplot are characterized by obscurity and are difficult to understand.

5.7 Visuals as reinforcers

The second characteristic of the KVs concerns how the visuals become reinforcers of the message. In other words, certain visuals act as message amplifiers. A reinforcer is a visual that operates with the intention of highlighting, making something more explicit, and quickly steering attention towards some specific information in either in visual or written form. Reinforcers (see Figure 11) could be the thick, red frame highlighting the white written text 'Import' or the green line on the scatterplot clearly showing the United States' development. Further, the years 1980 and 2008, when imports into the United States declined, are reinforced by red circles, red numbers, and arrows pinpointing the circles. This slide incorporates plenty of visuals as reinforcers.

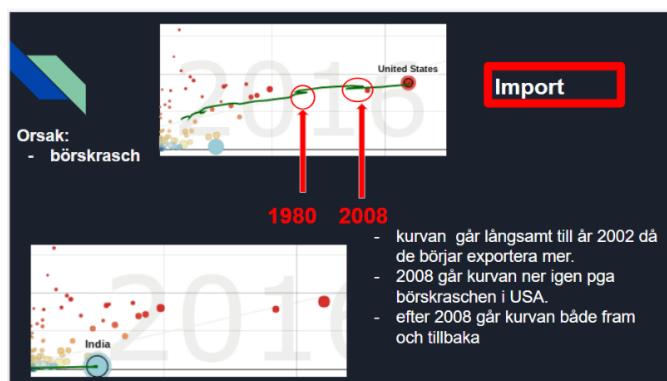


Figure 11. One slide in a KV where visuals including the red frame, red circles, red arrows, and green line act as reinforcers of both the demonstrated insights and the content (the headline).

It seems that the multimodal opportunities provided by visual actors such as colours, shapes, frames, and arrows at first strongly attract other actors in the network. However, later, interactions appear to be guided by a consensus that visuals which stand out and dominate too much are not beneficial. Hence, the students' visual abilities develop while producing KVs, and this is visible in several of the completed KVs, for example, in Figures 8 and 9.

5.8 Written text as a semiotic mode

The third characteristic of the KVs concerns written text as a semiotic mode, which is also part of the slide in Figure 11. The assignment was to produce multimodal KVs, with special focus on applying visuals in the presentations, but some written text is also present in most slides. For example, the text in Figure 11 contains statistical information about the world, but it also contains written information about causes and consequences. The written text is primarily displayed in headlines, keywords, and bullet lists and is placed next to the map or scatterplot to complement them. Hardly ever does the text stand on its own, except for a few, rare slides that consist only of written text (Figure 12). Interestingly, the insights that are expressed by written text do not stand on their own; they are also supported by visuals as reinforcers, such as the orange-coloured ellipses. These visuals highlight the words 'increased consumption' (*ökad konsumtion*) and 'Increased exports' (*Export ökar*).

Konsekvenser!

1. Bättre ställt (ekonomiskt)-**ökad konsumtion**- koldioxidutsläpp- global uppvärmning- polerna smälter- översvämningar- stora städer vid kusten- samhällets ekonomi negativt- ex skador på el nät- enskilda individer- hus förstörda- myndigheter ej tid/råd- individer flytta- plast, myndigheter/hjälpororganisationer- stress
2. **Export ökar**- gynna landets ekonomi- inte bara exportera mycket- exportera rätt=hel/halvfabrikat- länderna, höjde GNI- stabil ekonomi- utveckla t.ex. välfärden- enskilda individer- bättre sjukvård- skaffar färre barn- barn åldrarna 0-5 färre

Figure 12. A slide in which written text is the dominant semiotic mode, but the insights are visually reinforced by the orange-coloured ellipses.

The mobilization of the multimodal arrangement (KV) is characterized by visuals as carriers of information, visuals as reinforces, and written text as a semiotic mode. The finished DPs can be interpreted as constrained networks created by a multitude of actors, which in turn corresponds to the networks entering the final moment in the theoretical translations process: mobilization. As the actors are reassembled and arranged in the mobilization moment, they become readable; they are able to ‘speak’ in the name of others. The students’ insights are visually communicated.

6. Discussion

The results of our investigation show how the networks manage to translate insights from interactive visualizations into multimodal arrangements (KVs) and what characterizes them. The networks consist of a multitude of actors, all interacting with each other. At first, the visualizations, students, cursors, text documents and other actors are all dispersed and not easily accessible. Through the translation moments, they are reassembled at a particular place and time, and this is what finally happens in the completed KVs. The visualizations are translated to maps and bubbles with arrows, frames et cetera as highlighters. The written text is translated into bullet lists, key words, and headlines. The layout of the slides is arranged and rearranged several times. Hence, actors are displaced from the VA and the text document and are transformed into a social science presentation through a series of translations. As the actors are reassembled, all the particular KVs become in the mobilization moment spokespersons who are able to represent and ‘speak’ in the

name of others. In the classroom practice, this means that the students' translated insights from the VA, arranged and expressed by different visuals and text, now can be communicated to other students and teachers through the KVs. When the actors allow a KV to speak in their names, they are rendered mobile (Callon, 1986). For example, represented by the KV, the actors can be transported to a whiteboard and participate in an oral presentation and then be sent to, or placed at, the learning platform for the teacher to assess.

The role of such networks demonstrates the importance allowing students to explore the applications on their own. At the same time, it is important that they are not left entirely to themselves, that they can share experiences with other students, and that teachers guide them, for example, in discovering the applications' different features. Being new to the technology, the students pay attention to both other students and the teacher when exploring its functions.

The pattern of gathering comprises similar elements: the importance of demonstrating the different parts of the application and discussing what content should be collected and how to store it. Another example in our study is the value of teachers talking with the class about what visuals can show and offering a productive comparison between the use of keywords and limited images, explaining that the latter, like keywords, do not contain enough information to be useful to the viewer/reader. As the students become more comfortable, they tend to skip a specific document for making notes and instead move directly from the VA to their growing KV. We expect there may be pedagogical gains in moving directly between these two types of visualization.

As the insights are inserted into the KVs, the pattern of inserting through arranging and rearranging once again demonstrates the importance of allowing students to interact on their own, like in the event with the drawing functions. The visual playfulness appears to be supportive in the development of visual skills. Had this process been stopped and those types of drawings not allowed, the improved screenshot, as exemplified in Figure 8, would not have been possible.

The three identified patterns correspond to common traits in how the efforts within the networks evolve. At the same time, they are non-linear, that is, they are established in the order exploring–gathering–inserting; thereafter, they appear in mixed orders during the process of producing the

KVs, which is in line with Tergan et al. (2006) and Crawford (2012). As revealed, when a network produces a KV, it supports students in developing skills that increase their abilities to handle such visualized data.

As a response to the question regarding characterizations of students' mobilization of multimodal arrangements like KVs, we conclude that they are generally information *rich*, that the visuals are either carriers of information or used as reinforcers of the message, and that written text is used as a semiotic mode to complement the visuals. However, although the network manages the technology and can translate information and conclusions into multimodal presentations, there are also difficulties. In this study, there are examples of where visuals in the KVs are too narrow and lack information to such a degree that they cannot be understood. This result is in line with Säljö (2010) and Molin (2020), who assert that new types of digital and multimodal texts are supportive but call for the ability to understand and synthesize information – to transform and produce information. Accordingly, in order to take advantage of modern VA and KV and nurture their use, there is a need to develop strategies to support students in their efforts to communicate insights from 'reading' an interactive and multimodal screen to 'writing' in a compatible mode, namely, producing multimodal presentations that teachers can examine when assessing students' knowledge. There also follows a need for teachers to adjust their teaching towards the new digital technologies. The examples given in this article clearly indicate that students can achieve 'things' (presentations containing and combining visualized statistics, symbols, bullet lists, and text fragments) in ways such that the content can be judged to be acceptable, readable, and combinable (Latour, 1990). The network processes followed in this study can hopefully shed light on how to develop strategies – for further research, teacher training, and schools – on how to, as Ryan (2016) puts it, support and encourage visual discoveries.

This study also strengthens findings that pedagogical methods of assessing primarily written texts handed in by students will have to be adjusted in relation to the multimodal options that interactive visualizations offer, as pointed out by Elf et al. (2018), Baldwin (2016), and others. Such multimodality requires not only more flexible and modifiable modes for students to present and

share the knowledge they have gained but also other approaches for teachers to assess students' achievements.

This study was directed towards the translation from visualized statistics to KVs, but as has been shown by others (e.g., Eppler, 2013; Seifert et al., 2014), such presentations can also serve as important stages in knowledge-acquisition processes. The results verify the need to further develop how knowledge can be identified and presented in general terms, as pointed out by Bertschi et al. (2011).

This study was conducted as an innovative implementation in a collaboration between teachers and researchers within a DBR approach. It is important to conduct similar studies on a larger scale in more classrooms because things are likely to change and appear differently when applications of both VA and KV become more common. On the other hand, studies during the early stages are also important because they can influence future developments in fruitful ways. Development work can be much more powerful if it is informed by research and early experiences, even when those are based on rather novel steps and in a limited context.

Another avenue for further research that was reinforced by our study, and others (e.g., Pennycook, 2017), is the fact that sensory (bodily, visual, or oral) experiences cannot be separated from materiality. Sefton-Green (2021) has already pointed out that different challenges emerge when boundaries between textual forms become blurred by digital technologies. Some of these challenges definitely concern the implications for schools, which calls for further studies with more teachers and students in different (national) environments.

7. Conclusions

This study set out with the comprehensive aim of detecting patterns in how KVs are produced and arranged multimodally. Grounded in a DBR approach, the study has answered the research questions by identifying relevant patterns in the translation processes and characterizations of multimodal arrangements. However, the results are far from conclusive, and there is an urgent need for complementary research on the use of VA and KVs on a larger scale, in more classrooms, and with different applications.

Theoretically, this study contributes to the development of a growing number of network analyses in educational environments. Primarily, the value of employing such an analysis lies in the ambition to deepen our understanding of the processes involved in the visualization of information and how to support relevant skills within the educational system. In this study, the network approach has been invaluable, for example, in revealing the intrinsic web of relations within a translation process.

To prepare young people for their future life as citizens, it is crucial that the use of VA and KV applications in schools expands. Studies during the early phases are important for school development as a whole, and they may also have an impact on policy and curriculum development. Early research also reduces the risk of overlooking students in such processes.

This study is limited in scope, and more research is needed, but it is obvious that multimodal systems, such as the KVs in this study, support students to a greater extent because they allow them to express themselves in more than static modes such as written text. It is vital to remember that expressing oneself visually requires visual abilities, which need to be developed within schools alongside traditional writing skills.

References

- Aagaard, T., & Silseth, K. (2017). Teachers' assessment of digital stories: Challenges and dilemmas. *Nordic Studies in Education*, 37(03–04), 231–242. DOI: <https://doi.org/10.18261/issn.1891-5949-2017-03-04-08>
- Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research? *Educational Researcher*, 41(1), 16–25.
- Andrienko, G., Andrienko, N., Keim, D., MacEachren, A. M., & Wrobel, S. (2011). Challenging problems of geospatial visual analytics. *Journal of Visual Languages & Computing*, 22(4), 251–256.
- Baldwin, K. (2015). Assessing the new media rhetoric: Crossing disciplinary boundaries. In A. T. Demo (ed.) *Rhetoric across Borders* (pp. 245–253). Anderson, SC: Parlor Press.

- Baldwin, K. M. (2016). *Multimodal Assessment in Action: What We Really Value in New Media Texts*. Amherst: University of Massachusetts.
- Bearne, E. (2009). Multimodality, literacy and texts: Developing a discourse. *Journal of Early Childhood Literacy*, 9(2), 156–187.
- Bertschi, S., Breschiani, S., Crawford, T., Goebel, R., Keinreich, W., Lindner, M., Sabol, V., & Vane Moere, A. (2011). What is Knowledge Visualisation? *Perspectives on an Emerging Discipline. 15th International Conference on Information Visualisation, IEEE*. DOI:10.1109/IV.2011.58
- Breschiani, S., & Eppler, M. J. (2015). The Pitfalls of Visual Representations: A Review and Classification of Common Errors Made While Designing and Interpreting Visualizations. *SAGE Open*. <https://doi.org/10.1177/2158244015611451>
- Bezemer, J., & Kress, G. (2016). *Multimodality, Learning and Communication: A Social Semiotic Frame*. London: Routledge. DOI: <https://doi.org/10.4324/9781315687537>
- Bodén, U., & Stenliden, L. (2019). Emerging Visual Literacy through Enactments by Visual Analytics and Students. *Designs for Learning*, 11(1), 40–51. DOI: <http://doi.org/10.16993/dfl.108>
- Brownell, C. J. (2020). Disentangling the possibilities, practicalities, and progressions of writing in the contemporary (digital) era. *Theory into Practice*, 60(2), 160–171. DOI: [10.1080/00405841.2020.1857140](https://doi.org/10.1080/00405841.2020.1857140)
- Burkhard R. A. (2005). Towards a framework and a model for Knowledge Visualization: Synergies between information and Knowledge Visualization. In: S. O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization: Lecture Notes in Computer Science, vol 3426*. Springer, Berlin, Heidelberg. DOI: [10.1007/11510154_13](https://doi.org/10.1007/11510154_13)
- Callon, M. (1986). Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St Brieuc Bay. In J. Law (Ed.), *Power, Action, and Belief: A New Sociology of Knowledge* (pp. 196–233). London: Routledge & Kegan Paul.
- Callon, M., Law, J., & Rip, A. (Eds.) (1986). *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World*. London: MacMillan.

- Cederlund, C., & Sofkova Hashemi, S. (2018). Multimodala bedömningspraktiker och lärares lärande [Multimodal assessment practices and teachers' learning]. *EduCare*, 1, 43–68. DOI: <https://doi.org/10.24834/educare.2018.1.3>
- Comber, B. (2016). The relevance of composing: Children's spaces for social agency. In A. Haas Dyson (Ed.), *Child Cultures, Schooling, and Literacy: Global Perspectives on Composing Unique Lives* (pp. 119–132). New York, NY: Routledge.
- Cope, B., & Kalantzis, M. (2000). Multiliteracies: The beginning of an idea. In B. Cope & M. Kalantzis (Eds.), *Multiliteracies: Literacy Learning and the Design of Social Futures* (pp. 3–8). London: Routledge.
- Cope, B., & Kalantzis, M. (2010). New media, new learning. In D. R. Cole & D. L. Pullen (Eds.), *Multiliteracies in Motion* (pp. 87–104). Abingdon & New York: Routledge.
- Crawford, T. (2012). What is knowledge visualization? Eight reflections on an evolving discipline. In F. T. Marchese, & E. Banissi (Eds.), *Knowledge Visualization Currents: From Text to Art to Culture* (pp. 13–34). London: Springer Science & Business Media.
- Easterday, M. W., Rees Lewis, D. G., & Gerber, E. M. (2017). The logic of design research. *Learning: Research and Practice*. DOI:10.1080/23735082.2017.1286367
- Elf, N., Gilje, Ø., Olin-Scheller, C., & Slotte, A. (2018). Nordisk status og forskningsperspektiver: Multimodalitet i styredokumenter og klasserumspraksis [Nordic research perspectives: Multimodality in curricula and classroom practices]. In M. Rogne & L. Rune Waage (Eds.), *Multimodalitet i skole- og fritidstekstar. Ein vitenskapleg antologi* (pp. 71–104). Oslo: Fagbokforlaget.
- Elkins, J. (2008). Introduction: The concept of visual literacy and its limitations. In Elkins, J. (Ed.), *Visual Literacy*, (pp. 1–9). New York: Routledge.
- Eppler M. (2013). What is an effective Knowledge Visualization? Insights from a review of seminal concepts. In: Marchese F., & Banissi E. (Eds.), *Knowledge Visualization Currents* (pp. 3–12). London: Springer.
- Eppler, M. J., & Burkhard, R. A. (2007). Visual representations in knowledge management: Framework and cases. *Journal of Knowledge Management*, 4(11), 112–122.

- Felten, P. (2008). Visual literacy: Change. *The Magazine of Higher Learning*, 40(6), 60–64.
DOI:10.3200/CHNG.40.6.60-64
- Fenwick, T., & Edwards, R. (2010). *Actor-Network Theory in Education*. London: Routledge.
- Godhe, A.-L. (2014). *Creating and assessing multimodal texts: Negotiations at the boundary*. Diss. Göteborg: Göteborgs universitet.
- Hashemi Sofkova, S. (2019). Young students' reading paths of media: Semiotic focus as a strategy to guide educational practice. *AMIM 2019, Reading beyond Words: Approaches to Multimodality in the Media*, 12 April 2019, ArtsOne, Queen Mary University of London, London, UK. Book of abstracts, p. 10. 2019-01-01.
- Heath, C., Hindmarsh, J., & Luff, P. (2010). *Video in Qualitative Research: Analysing Social Interaction in Everyday Life*. Los Angeles, CA: Sage.
- Iedema, R. (2003). Multimodality, resemiotization: Extending the analysis of discourse as multi-semiotic practice. *Visual Communication*, 2(1), 29–57.
<https://doi.org/10.1177/1470357203002001751>
- Jewitt, C. (2014a). An introduction to multimodality. In C. Jewitt (Ed.), *The Routledge Handbook of Multimodal Analysis* (2nd edn.) (pp. 15–30). London: Routledge.
- Jewitt, C. (2014b). Different approaches to multimodality. In C. Jewitt (Ed.), *The Routledge Handbook of Multimodal Analysis* (2nd edn.) (pp. 31–43). London: Routledge.
- Kress, G. R. (2003). *Literacy in the New Media Age*. New York, NY: Routledge.
- Kress, G. R. (2010). *Multimodality: A Social Semiotic Approach To Contemporary Communication*. London and New York: Routledge.
- Kress, G., & van Leeuwen, T. (2001). *Multimodal Discourse, the Modes and Media of Contemporary Communication*. London: Arnold.
- Kress, G.R., & Van Leeuwen, T. (2006). *Reading Images, the Grammar of Visual Design*. (2nd ed.) London: Routledge.
- Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*/Bruno Latour. Cambridge, Mass.: Harvard Univ. Press, 1987

- Latour, B. (1990). Visualisation and cognition: Drawing things together. In: M. Lynch, and S. Wolgar (eds.) *Representation in Scientific Activity* (pp.19-68). Cambridge, MA: MIT Press.
- Latour, B. (1993). *We Have Never Been Modern*. Cambridge, MA: Harvard University Press.
- Latour, B. (2005). *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford: Oxford University Press.
- Law, J. (1987). Technology and heterogeneous engineering: The case of Portuguese expansion. In W. E. Bijker, T. P. Hughes & T. J. Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (pp. 111-134). Cambridge, MA: MIT Press.
- Law, J. (2004). *After method: mess in social science research*. (1. ed.) London: Routledge.
- Law, J. (2004). *After method: mess in social science research*. London: Routledge.
- Law, J. (2007). *Actor Network Theory and Material Semiotics*, version of April 25, 2007, available at: <http://www.heterogeneities.net/publications/Law2007ANTandMaterialSemiotics.pdf>, (downloaded on May 18, 2007).
- Law, J., & Hassard, J. (1999). *Actor Network Theory and After*. Oxford: Blackwell.
- Lundblad, P. (2013). *Applied Geovisual Analytics and Storytelling*. [Electronic resource]. Norrköping: Department of Science and Technology, Linköping University.
- Magnusson, P., & Godhe, A.-L. (2019). Multimodality in language education: Implications for teaching. *Designs for Learning*, 11(1), 127–137. DOI: <https://doi.org/10.16993/dfl.127>
- Massumi, B. (2002). *Parables for the Virtual: Movement, Affect, Sensation*. Durham, NC: Duke University Press.
- Meyer, R. (2009). *Knowledge Visualization. Research paper for the Media Informatics Advanced Seminar on Information Visualization, 2008/2009*.
- Molin, L. (2020). *Kritiskt digitalt textarbete i klassrummet*. Diss. Nr 81, Institutionen för tillämpad informationsteknologi, Göteborgs universitet.
- Nissen, J. & Stenliden, L. (2020). Visualized Statistics and Students' Reasoning Processes in A Post Truth Era. *Journal of Interactive Learning Research*, 31(1), 49-76.

- Pennycook, A. (2017). Translanguaging and semiotic assemblages. *International Journal of Multilingualism*, 14(3), 269–282, DOI: [10.1080/14790718.2017.1315810](https://doi.org/10.1080/14790718.2017.1315810)
- Purchase, H. C. (2014). Twelve years of diagrams research. *Journal of Visual Languages & Computing*, 25(2), 57-75. doi:<https://doi.org/10.1016/j.jvlc.2013.11.004>
- Purdy, J.P. (2014). What can design thinking offer writing studies? *College Composition and Communication*, 65(4), 612–641.
- Roll, I., & Wylie, R. (2016). Evolution and revolution in artificial intelligence in education. *International Journal of Artificial Intelligence in Education*, 26(2), 582–599.
- Ryan, L. (2016). *The Visual Imperative: Creating a Visual Culture of Data Discovery*. Cambridge, MA: Morgan Kaufmann.
- Sabol, V., Kow, W. O., Rauch, M., Ulbrich E., Seifert C., Granitzer, M. Lukose, D. (2012). Visual ontology alignment system: An evaluation. In *Proceedings of SIGRAD 2012, Interactive Visual Analysis of Data* (pp. 9–18). Vaxjö, Sweden.
- Sefton-Green, J. (2021). Is the re-contextualization of digital writing inevitable, escapable or desirable? *Theory into Practice*, 60(2), 116–125. DOI:
- Segel, E., & Heer, J. (2010). Narrative visualization: Telling stories with data. *IEEE Transactions on Visualization and Computer Graphics* 16(6), 1139–1148.
- Seifert, C., Sabol, V., Kienreich, W., Lex, E., & Granitzer, M. (2014). Visual analysis and knowledge discovery for text. In A. Gkoulalas-Divanis & A. Labbi (Eds.), *Large-Scale Data Analytics*, (IBM Research) (pp. 189-218) New York: Springer.
- Shipka, J. (2011). *Toward a Composition Made Whole*. Pittsburgh, PA: University of Pittsburgh. DOI: <https://doi.org/10.2307/j.ctt5hjqqk>
- Stenliden, L. (2014). *Visual Storytelling interacting in School. Learning Conditions in the Social Science Classroom*. Linköpings universitet
- Stenliden, L. (2015). Visual Analytics and K 12 Students - Emerging Dimensions of Complexity. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, 9(2), 663-671.

- Stenliden, L. (2018). Geovisual Analytics in School: Challenges for the Didactic Design of the Classroom. *International Journal of Information and Education Technology* (3), 178-185.
- Suthers, D.D. (2001). Towards a systematic study of representational guidance for collaborative learning discourse. *Journal of Universal Computer Science*, 7(3), 254–277.
- Säljö, R. (2010). Digital tools & challenges to institutional traditions of learning, technologies, social memory and the performative nature of learning. *Journal of Computer Assisted Learning*, 26, 53–64.
- TechSmith, C. (2010). *Camtasia Studio*. In (Vol. 7.1). Okemos, Michigan.
- Tergan, S.-O., Keller, T., & Burkhard, R. A. (2006). Integrating Knowledge and Information: Digital Concept Maps as a Bridging Technology. *Information Visualization*, 5(3), 167–174. <https://doi.org/10.1057/palgrave.ivs.9500132>
- Thomas, J., & Cook, K. (2005). Illuminating the path: A research and development agenda for visual analytics. In: *Visual Representations and Interactions Technologies* (pp. 69–104). IEEE Press.
- Tomaszewski, B., & MacEachren, A. M. (2012). Geovisual analytics to support crisis management: Information foraging for geo-historical context. *Information Visualization*, 11(4), 339–359.
- Treagust, D. F., Duit, R., & Fischer, H. E. (2017). *Multiple Representations in Physics Education [Elektronisk resurs]*. Cham: Springer.
- Tufte, E. R. (1997). *Visual Explanations*. Cheshire, CT: Graphics Press.
- Tversky, B., & Suwa, M. (2009). Thinking with sketches: Tools for innovation. In A. B. Markman & K. L. Wood (Eds.), *The Science behind the Practical Methods that Drive Innovation* (pp. 75–85). Oxford: Oxford University Press.
- United Nations, General Assembly (UN) (2014) *RES/68/261, Fundamental Principles of Official Statistics*. Retrived from <https://unstats.un.org/unsd/dnss/gp/FP-Rev2013-E.pdf>
- Wei, L. (2011). Moment analysis and translanguaging space: Discursive construction of identities by multilingual Chinese youth in Britain. *Journal of Pragmatics*, 43(5), 1222–1235. DOI: doi.org/10.1016/j.pragma.2010.07.035

- Kimber, K., & Wyatt-Smith, C. (2010). Secondary students' online use and creation of knowledge: Refocusing priorities for quality assessment and learning. *Australasian Journal of Educational Technology*, 26(5).
- Åkerfeldt, A. (2014a). Re-shaping of writing in the digital age-a study of pupils' writing with different resources. *Nordic Journal of Digital Literacy*, 9(3), 172-193.
- Åkerfeldt, A. (2014b). *Didaktisk design med digitala resurser: en studie av kunskapsrepresentationer i en digitaliserad skola*. English title: Didactic design with digital resources: A study of representations of knowledge in a digitalised school Stockholm: Institutionen för pedagogik och didaktik, Stockholms universitet.