Visual Analytics in K 12 Education - Emerging Dimensions of Complexity

Linnea Stenliden

Abstract—The aim of this paper is to understand emerging learning conditions, when a visual analytics is implemented and used in K 12 (education). To date, little attention has been paid to the role visual analytics (digital media and technology that highlight visual data communication in order to support analytical tasks) can play in education, and to the extent to which these tools can process actionable data for young students. This study was conducted in three public K 12 schools, in four social science classes with students aged 10 to 13 years, over a period of two to four weeks at each school. Empirical data were generated using video observations and analyzed with help of metaphors within Actor-network theory (ANT). The learning conditions are found to be distinguished by broad complexity, characterized by four dimensions. These emerge from the actors' deeply intertwined relations in the activities. The paper argues in relation to the found dimensions that novel approaches to teaching and learning could benefit students' knowledge building as they work with visual analytics, analyzing visualized data.

Keywords—Analytical reasoning, complexity, data use, problem space, visual analytics, visual storytelling, translation.

I. INTRODUCTION

A part of the task of education that teachers and students entail is dealing with data and analyze information in order to understand the world. Today, this is perhaps more complicated than before and the challenge is renewed as the volume of data and information is tremendous and growing at a rapid pace [1]. Digital data are everywhere, in every sector, in every economy, and in every organization and institution. The ability to store, aggregate and combine data and then use the results to perform analyses has therefore become essential [2]. Furthermore, the scale and scope of changes that the fast proliferation of data is bringing about are set to expand greatly, as various technology trends accelerate and converge [3]. All of this places great demands on education [4]. Teachers and students face puzzling conditions to teach and learn about the world, especially in relation to social science education, but also to other subjects. One challenge is to develop education that supports the students' learning about how to analyze information in order to get grip of the compound world of today.

As new methods and technology, as visual analytics (VA), are developed with the aim to cope with the information overflow these may offer support in reaching some of the teaching objectives in school in relation to contemporary conditions. VA is not only an umbrella term for technology

Linnea Stenliden is with the Department of Social and Welfare Studies, Linköping University, Linköping, SE602 18 Norrköping, Sweden (phone: +46 70 085 07, e-mail: linnea.stenliden@liu.se).

that attempts to visualize information; reinforce analytical reasoning; argumentation and knowledge building [5], [6]. It is also the name of emerging interdisciplinary research which integrates perspectives from Geographic Information Science (building on work in geovisualization, geospatial semantics and knowledge management, geo-computation, and spatial analysis) and Visual Analytics (grounded in Information and Scientific Visualization), [7]. In this study a VA (Fig. 1), is introduced to social science teachers for use in their teaching. This technology can be seen as offering means to both support teachers' "transposition" of "raw material/information" [8] and students' "visual analytical reasoning" [9].

An introduction of a technology in an educational setting like this study, will always affect other parts in some ways, but in what direction this happens is hard to foresee [10]. Therefore, it becomes important to find out what conditions that actually will emerge in education if a VA is introduced. This may help teachers to meet the demands to develop students' ability to handle and analyze large amounts of data [2] and it can make valuable contributions to both instruction and processes of learning [11]. To explore this, the learning activities are examined by involving a VA in K 12 social science classrooms. The aim is to understand emerging learning conditions when a VA is employed in such educational environments. More specifically the following questions are asked:

1) How do the data communication technology, the task characteristics and school children interact, when methods for visual storytelling technology are employed in social science education?
2) What characterize the translations and occurring problem spaces, when methods for visual storytelling technology are employed in social science education?

Notably is, that learning conditions are in this paper seen differently from i.e. [12] that has long been associated with this phrase. Reference [12] describes learning conditions as internal and external. The internal condition exists within the learner and are his or her existing capabilities, and the external conditions include the stimulus's that exist outside the learner such as the environment, the teacher, and the learning situation.

Instead, by using an ANT perspective in this study, the learning conditions are seen as constructed by assemblies or gatherings of myriad actants (learners, technology, assignments etc.) that exist in the educational practice. The classrooms, teachers, students, the teaching, the knowledge generation, curriculum, policy, standardized testing, inequities, computers, etc. together interacts and it is these

(possible) interactions that order, govern and stipulate the learning conditions. The learning conditions are with this approach therefore seen to emerge from all interactions and negotiations between all actants [13] (for further discussion see Section III).
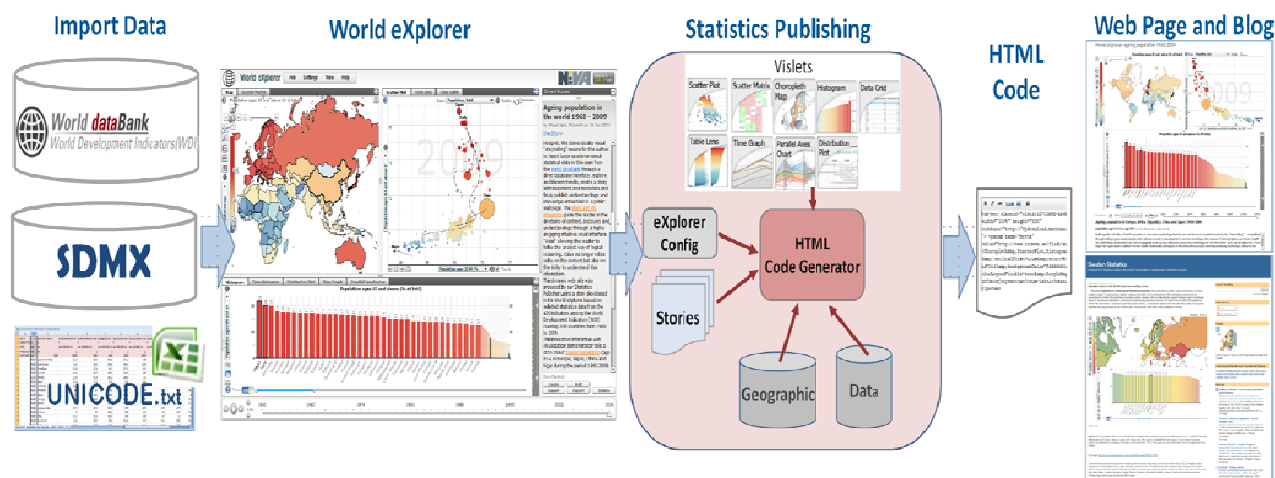

Fig. 1 The VA introduced, is the Statistic eXplorer platform, which makes it possible to: import statistical data from official databases; explore and gain insight in the data; create a visualized story and publish the visual story at a blog or a web page

II. Developing Students' World Views

In a world flooded of information the importance of developing students' world views, civic knowledge and participation in society, has led to discussion on what actually promotes this kind of knowledge. Reference [14], claim that students are not always being provided with a consistent view of the world. Therefore, education may adapt new practices at the classroom level and adjust the practice to new requirements associated with technology use and awareness [14], [15]. Lately, some VA tools have been applied to educational activities in schools. This is to support problem solving activities associated with a processing of large quantities of data in order to analyze information and promote an adequate development of students' world views. Most discussions of this kind of data use so far, have focused on system evaluation rather than on improving students' learning or the teaching practice [11]. References [16], [17] demonstrate though how data-rich settings, like VA, make the learning process complex in character in relation to the practice of problem solving in schools. [18]. This practice of solving problem solving and problem-centred tasks is central in social science education as students' competencies of reflection on interdisciplinarity and self-reflection-as-citizen are key tools for analyzing societal problems and to act democratically.

Accordingly, students are expected to solve these kind of tasks by searching for, as well as translate and form information into knowledge, but also to put it into new products (formulate texts, create posters, prepare digital presentations, etc.) [15], [19]. The activities concerning these assignments are since the 1990s often dominated of a student centered mode of operation, at least in a Nordic context where this study is conducted [20]. According to [14] this approach is often un-problematized both in governmental documents as well as in classrooms. Reference [20] argues that this practice matter to students and shape how they search for and treat information. Usually the students' activities in this kind of practice start by different kinds of information searches [21]. Nowadays, students' information searches often involve using the web [22], even if text still is the dominating mode in school [20]. When using the web, the searches usually start with Google [23]. This often creates problems both for students and teachers in finding relevant written material that suits the younger students. The students also seem to need a lot of support during their searches, which is often an underestimated issue [19], [24]-[28].

Social science teachers have a pivotal role in designing the subject area where the didactic design usually is aligned to curriculum and course criteria [15]. Reference [29] explains how the "raw material" has to be transformed, shaped and constructed to offer information/content that suits the teaching situation and the current student group. Also the pedagogical and methodological advice depends on the "raw material" and has impact on the choices of teachers' actions. Hence, also the choice of work model depends on the content of the educational situation and goals for the lesson. Reference [8] has introduced the Norwegian concept "omstilling" (transposition) to explain the "transposition" of the "raw material" to concrete teaching material and actions. He argues that a qualified teacher do this "transposition" of the domain specific knowledge continually. It is plausible to see teachers' ability of "transposition", their subject didactical knowledge, as central to the teaching competence performed in classrooms [29]. Altogether, this creates questions about the learning mode that takes place when trying to develop students´ world views that as showed is rather intricate. The research questions asked in this paper concern the complexity that emerges when

a VA is introduced in social science education. To be able to answer them, the actor-network theory (ANT) has been used [30].

III. ACTOR NETWORK THEORY - A THEORETICAL STANCE

By drawing on ANT in this paper, the emergence of conditions for learning are investigated and analyzed in relation to how both social actants (teachers and students) and material actants (technology as well as other objects and matters) form activities [10]. With this *approach it is possible to study* how social and material action together performs a particular enactment, rather than focus on the humans' interaction with artefacts, their use of the tools [13], [30]. This means, that the *interactions between* the different actants (students, technology, teachers, educational content, assignments etc.) become significant [13]. The interactions of the actants constitute a network, which emerges due to the ability of the different actants to align in pursuit of their interests – the learning conditions.

A. Learning Conditions, Learning Activities, and Interactions

The learning conditions are, as explained, seen as distributed in the networks of the actants and through the interactions from where they emerge [31]. This means that the activities are not seen to be performed under established conditions in a social context, instead it is the possible actions of all actants that are seen to construct the learning conditions

in the environment: the network. This paper is based on the presumption that there is no separation between the students, the tasks and the task context: the social and material actants. What is studied is how the actants act/engage in collaborative tasks and the term learning activity [32] refers to all interactions between the actants.

B. Translation and Problem Space

Within ANT manifestations of the actants' interactions are called *translations*. These can be of different character, but have in common that they are used to tie the actants together [13], [33]. A translation can be seen as having different characters.

1) *Problematisation* happens, where an actant attempts to define the nature of the problem and the roles of other actants to fit the solution proposed.

2) *Interessement* can take place in a series of processes that attempt to impose the identities and roles defined in the problematisation onto other actants.

3) *Enrolment* may ensue, and leads to the establishment of alliances among the actants. For enrolment to be successful however it requires more than just on set of actants imposing their will on others; it also requires these others to yield.

4) *Mobilisation* can occur as the proposed solution gains wider acceptance and an even larger network of absent entities is created through some actants acting as spokes-persons for others.
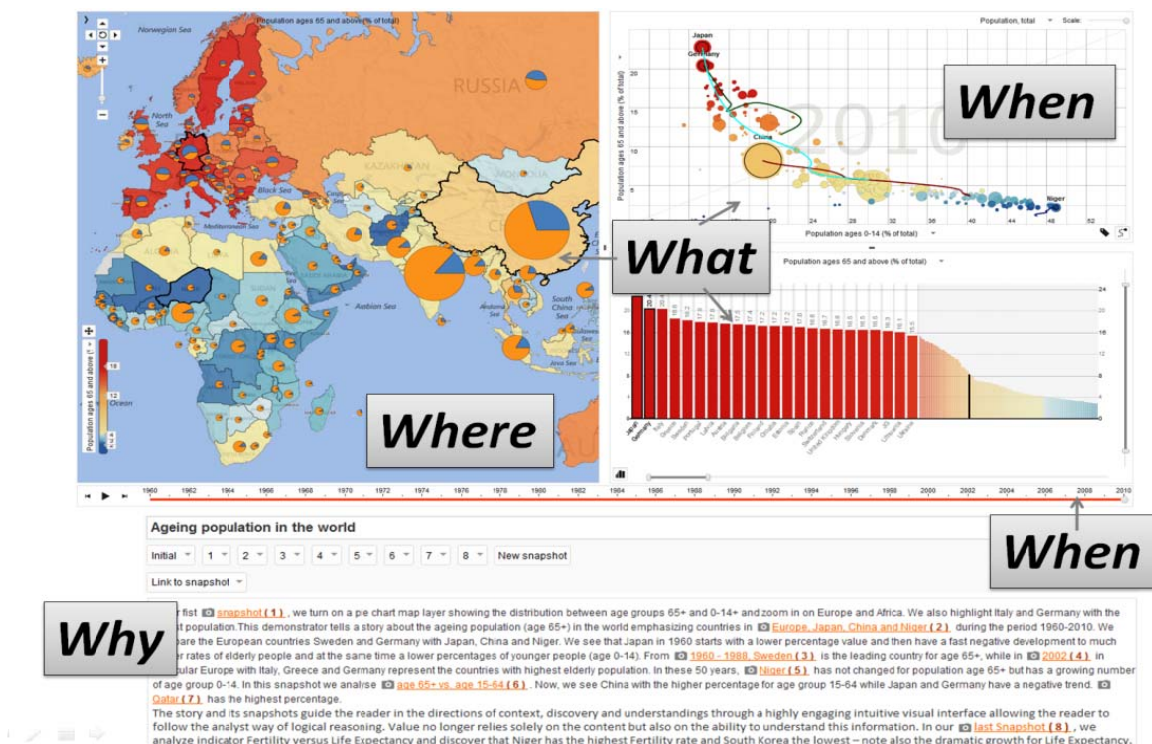

Fig. 2 Multiple views dashboard visualization with associated storytelling panel based on statistical national data from the World DataBank explaining the statistical content in relation to where, what, when and why

So, every connection through interaction between actants is a part of a translation and causes a transformation of what has been articulated. This is not necessarily a sequential process and a translation does not always mean a complete translation. In this study the term problem space is used to embrace the situation that can occur in a translation before it has fully succeeded, if it succeeds at all (cf. [34], who define the term slightly different due to a different theoretical approach). The term is in this study used to embrace the moments when a student and other actants attempt to define the nature of the problem and the roles of other actants to fit the task of the assignment. These conceptual metaphors: *translation* and the concepts for its characters *problematisation, interessement, enrolment* and *mobilisation* as well as the term *problemspace* are analytical tools that are used to describe the associations between technology, students, teachers and classrooms.

IV. METHOD

The study was carried out in three different K 12 schools in Sweden. The choice of schools can be seen as a purposeful random sample of schools, as the goal was credibility, not representativeness or the ability to generalize [35]. All K 12 schools in a municipality were invited to participate in the study with their social science teachers and all the teachers who volunteered were allowed to join. Altogether, four teachers and their four classes, comprising 98 students aged 10 to 13 years participated. The VA tool used was the Open Statistics eXplorer platform [36]. The learning activities were followed in all social science classes during a period of two to four weeks at each school.

A. Data Communication Technology

The Statistics eXplorer platform has a conceptual approach based on three complementary activities: a) data down-load, b) storytelling and c) publishing [36]. Official statistics data, are normally preloaded from official databases (with a set of basic indicators) [37]. The visualizations facilitate information and geographical visualization methods (Fig. 2).

The platform's storytelling functions allow teachers to gain insights and customize the data download. Discoveries that the teacher makes can be documented with snapshots and associated descriptive meta text, and accessed via hyperlinks, also external web links to relevant information can be attach that may contribute to a more complete understanding of visual story (Fig. 2). It is possible then to use a publisher tool to publish the educational material as interactive stories on a blog or a web page. The published material is called a 'Vislet': a small visualized digital book with an interactive and Dyna Linked interface (Fig. 3)

B. Data Use, Data and Task Characteristics

The study was conducted in two phases. In phase one, the teachers were introduced to the Statistics eXplorer platform. Six different occasions were organized for the training of the teachers, where they learnt how to man oeuvre the visual storytelling features. A webpage with course material was created in co-operation with the National Centre of Visual

Analytics (NCVA) for this training [38]. The teachers made lesson plans according to the Swedish social science curriculum; down-loaded official statistics in relation to the educational goals and organized the content and the tasks by involving the visual storytelling methods. The official statistics that the teachers chose to interact with came from databases related to Statistics Sweden (SCB), the Organization for Economic Co-operation and Development (OECD), the World Health Organization (WHO) and the World Data Bank. The Vislets that the teachers produced were published on a blog shared by the participating schools (Fig. 4) [17]. The Vislets, created by the teachers, contained information about three different levels: national, continental and global. They concerned 1) living conditions in Sweden – differences and similarities, 2) living conditions in Europe, focusing on aspects of population, education, work and economy, and 3) global characteristics such as energy use, water access, and environmental issues. In addition to the interactive official statistics, various stories and assignments were included. These stories concerned socio-scientific issues as described or made comparison of own living conditions with people in the rest of Sweden, Europe or the world. The assignments were different types of problem-solving questions regarding circumstances of life and reasons to these in relation to a) energy use, b) water – access to and use of freshwater, c) "poor and rich countries" – population growth, expected length of life, infant death, d) population, e) the environment – CO_2 effluent and economic, etc.

In phase two, the teachers used the Vislets in their social science classes. The learning sequences usually began with the teacher introducing the content or instructing the students on how to proceed. Then the students worked in pairs. They tried to solve the assignments posted by the teacher at the Vislets. The students' access to computer technology varied. The classrooms were equipped in three different ways: one had five stationary computers; one had a laptop connected to a smart-board and students had access to a form room equipped with desktop computers; and a third classroom (used by two of the classes separately) had 15 laptops and a digital projector

C. Data Gathering

Documentation and analyze methods that advance knowledge of the actants' interactions and their relationships during the activities are of particularly interest when studying the use of media technology [39]. In response to this, video observations were made which facilitated thorough documentation of the actants [40]. All lessons in the social science classes were followed with an ordinary video camera.

Also recordings with the computer's web cam, audio recordings by the computer's microphones as well as recordings of the computer screens were made by Camtasia Studio [41]. Hereby it was possible to in detail capture what was happening also on the screen of the computers. In all, the empirical material constitutes by 42 recordings of sessions taken at close range, showing students together with computer screen captures (22.2 h), and 35 overview recordings of the classroom (16 h).
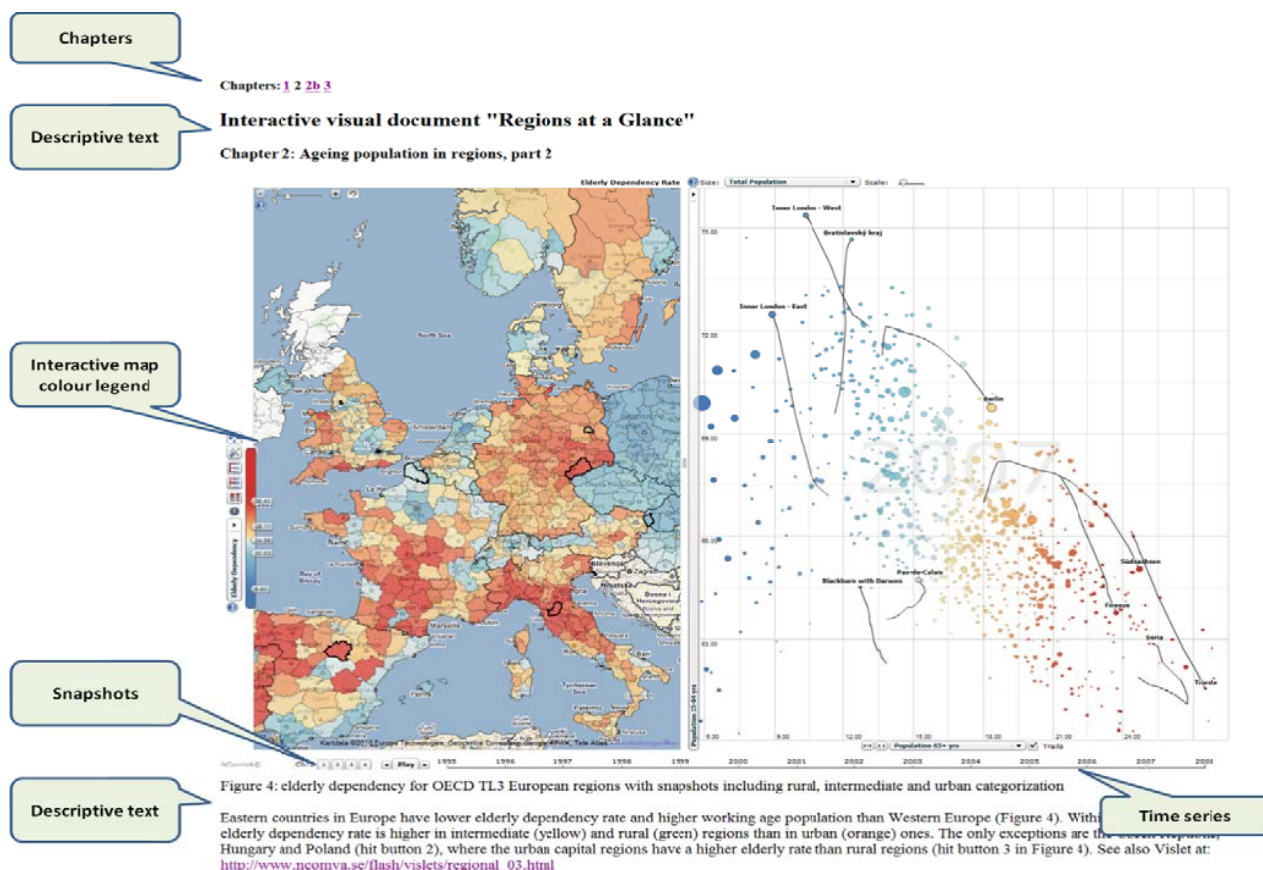
Fig. 3 A visual story that is created by a teacher, it becomes a Vislet when it is published at a web page of a blog

D. Analysis

To guide the analytical work, *three* principles highlighted by Callon [42] were used. The first, a matter of style means not to censor the actants (teachers, students, the application, official statistics etc.) selectively, when they expressed themselves. Consequently no pre-defined analytical classes have been used to the montage of data. The pieces selected for analysis can be said have invited the researcher, in some way to "handle" its contents and by what is called intensification [43]. The second, generalized symmetry means that the same vocabulary should be used to describe social and material objects. Therefore the terminology is carefully considered. The third, free association means to abandon all a prior distinctions between natural and social events and thus its tried not to make disjuncture between different actants and their actions.

An early finding among the learning activities in the material was that different kinds of problem spaces appeared frequently all through the material. Accordingly, a sample of the empirical data has been analyzed byusing the metaphors earlier mentioned: *translation*, *problematisation*, *interessement*, *enrolment* and *mobilisation* as well as the term *problem space*. The focus was on all learning activities in the networks, as they characterize practical action.

V. RESULTS

The analyses show that the learning conditions emerging in the classrooms are constructed by deeply intertwined relations between different actants (by their interactions). Several problem spaces are found within the manifestations of the actants interactions and four dimensions of complexity appear in the translations and characterize the phenomena. These aspects of the learning conditions; the problem spaces and the dimensions of the complexity are illustrated by empirical examples in the following subsection. More specific, this subsection will answer research question one and two. The later subsection summarizes the results in relation to the aim of the paper to support an understanding of the results as a whole.

A. Dimensions of Complexity

By a detailed analysis of the actants' translations (in the learning activities) four different dimensions of complexity appear, at least, and they are present all through the empirical material. In the following excerpt the task to be performed by the technology and two students, Emma and Jasmine, is to find the ten largest municipalities in Sweden.

Emma and Jasmine read the assignment posted at the Vislet. The map on the computer screen shows the location and land area of the municipalities in Sweden. The population distribution is also indicated by a colour scale for these areas

on the map. The students look at the dyna-linked interface. They focus the scatterplot where dots at different places and in different colours and sizes according to indicators at the y- and x-axes articulate information of the municipalities. They ignore looking at the map. Before long, the students raise their hands and ask their teacher for support in adjusting the indicators in the diagram.

The students here attempt to find out what action to take with the school assignment. By this doing a problem space immediately arises. They try to define the nature of the problem and the roles of other actants. This is a short moment of problematisation – the students conclude in some way that they should adjust the indicators, but they do not know for sure how. Their decision: to attempt to adjust the tool, takes them into – the moments of interessement. The students want to investigate in what way that the actants – in this case the features of the Vislets – can support in solving the assignment. But as the excerpt illustrates, the students don't have the required knowledge or experience to adjust the indicators at the diagram axes. In this case they enroll with another actant, they ask for support from their teacher in adjusting the tool. Together can this be related to *an information processing complexity* that is caused by the demands of the technology [34]. The students have to be able to manipulate the tool to find the requested information. Then the learning activities can go on, this is illustrated by the following excerpt. The students have now had instructions from the teacher.

Emma, the mouse and the cursor cooperate to adjust the indicators. The scatter plot changes and articulates population on both axes and shows all the bubbles in a row. These bubbles articulate now the name of the municipality and the number of people living in the different municipalities. The students look at these and immediately and eagerly they click on the bubble at the top of the row. The bubble indicates Stockholm, and the students align to this as they read the text articulating that. They also read it aloud and they then try to say the number of people, which is articulated by figures. This is a large number that they have a problem to spell out. Jenny says interested while pointing at the numbers articulating at the screen: - Which is the largest? Stockholm or that?

This shows how the students try to impose the identities and roles that they found in the problematization onto other actants (the indicators). But, a problem space arises as they hesitate in the meaning of largest in the task question: should they identify the name of the municipalities that are largest in area, or the ones that have the largest populations? This can be seen as linked to *an objective task complexity* that depends strictly upon the characteristics of the task itself [44], [45]. The tool articulates both kinds of information and the students seem unsure of how they should read the articulations on the screen. The alternative options create a complexity featuring *a lack of structure* which can be seen as representing the degree to which the task is fully understood [34] and in what way the roles of the other actants can be a part of or fit the solution to solve the task. The following excerpt shows this.

Just a moment later Jasmine and Emma stop focusing the numbers and the cursor start to move over the bubbles from the top, then each below one another. The bubbles articulate the names of municipalities, and the students say the names one at a time as they go through them. They also use the zoom function to separate the bubbles when necessary and Emma finds the answer. They also confirm their learning process by comparing the bubble with the corresponding area at the map. With a mouse click a boarder turns up around the area and the corresponding bubble at the diagram. In the same moment as they have gone through the municipalities. Emma remembers that they are supposed to write down the answers. Sighing heavily, the students put up their hands to get the teacher's attention, instead of start writing.

Instantly, when the indicators are adjusted, the phase of interessement is actualized again (the students have to identify in what way other actants can support further solution). The students try to find out how to read the data type: the image and the colours of the diagram and the semiotic messages they contain. However, the students are not familiar with numbers this large, so they abandon that line of action by avoiding that path. Instead, they chose to enroll with the tool by investigating the other bubbles reading the name of the municipalities. The students assume that a bubble at the top of the diagram indicates that something is the largest amount. In this moment, an establishment of alliances occurs among the actants – an enrolment. By their assumption of how to read a diagram they are able to proceed in the translation. They confirm the found answers (starting with Stockholm) by using the information of the bubbles together with the information provided by the dyna-linked view, which offers markings of the communities on both the scatter plot and the map. It is not the largest area at the map but the area that are deepest red in colour. By this it is possible, to a certain degree, to say that a translation has been completed. The information has been processed by interactions between the students, the Vislet, the teacher, the data, the semiotics, etc. A mobilization seems to be possible, as the proposed solution has gained acceptance and an even larger network of absent entities could be created (the solution could be communicated by different actants/ means/modalities to other actants). Despite this, at the same moment when the students find the answers and remember that they have to transfer the information from the screen onto paper, they utter a deep sigh. This utterance is interpreted as signaling a problem with the mobilization. This adds an *experience complexity*, which is defined in terms of what the task performer experience [34]. The students seem to apprehend the task of transferring the visualized information from the screen, which they just have translated with, onto paper as something tricky, difficult or boring. They have to get the attention of, and discuss this with, their teacher. This is understood as follows: the students are able to align to the visible information. They can translate and understand it even if it is complex, but it seems complicated for them to transform it into another modality, as text-based information. To fully succeed with the school assignment the students have to enroll with an even larger network, the teacher has to align with the actants.

The above demonstrate that, even in a task with low

discretion like this, different dimensions of complexity are found to emerge in the learning activities. The dimensions found can be defined as: *information processing complexity; objective task complexity; complexity featuring a lack of structure and experience complexity*. Hence, the learning conditions in the studied classrooms where a visual analytics is used/interacting end up being multifaceted. However, the learning activities in the network are generally directed to solve or sort out the entwined dimensions in the problem spaces.

B. Emerging Learning Conditions

The actants in the social science classrooms where a VA is interacting have been shown to together create multifaceted learning conditions that are distinguished by highly complex relations between the actants. In the activities various problem spaces emerge and different dimensions of complexity are found that characterize them. The dimensions of complexity vary as the translation in a problem space change. But, this is not a linear process. Instead, the dimensions of complexity are featured by the actants' interactions in the emerging problem spaces (in the translations, in the learning activities). The technology seems most often though, to enhance students' ability to sort out the emerged complexity. They are able to find relevant information and make analyses of the visualized content together with the screen and the interactive features.

However, one of the dimensions of complexity, the experience complexity, pointed in another direction where the problem space relates to the production of text based answers. The assignments usually demanded the students to turn their analyses of the visualized information into this other modality - into written text. While working on these, at all times student-centered learning tasks, the students seem to lose some of their grasp of what emerged in the learning activities. *The task to transform the visual analysis to text was often too complex for them.*

Consequently, this kind of problem space didn't open up for constructive actions as the task performers' experiences resulted in a cessation of the interactions – they required frequently in these cases the teacher's assistance. Possible reasons for the obstacles are: the ground for the analyses is complex (cf. the four dimensions of complexity found); the students do not deepen their analytical reasoning enough (in the empirical example not at all). Writing is a complex assignment in itself (the students did not even try to formulate a written answer instead they requested help from their teacher) and that all these factors inter-operate. Accordingly, time is required for reflection on the complexity of the content; time is needed for discussion to deepen the understandings; time is needed for considerations of how to present the conclusions in the new modality, if a textual one is needed at all. As a conclusion, approaches to teaching and learning in social science education, where a VA interacts need reflections.

VI. DISCUSSION

This article regards specific challenges of contemporary education brought about by the access to information resources, the opportunity to engage with big data and demands to build information skills [2], [3], [11]. A conclusion from this is that education may support students' how to deal with technology that is developed to analyze vast information masses. This is to reinforce them to get grip of the compound world of today and to be able to participate in society. Therefore, a VA was introduced to social science teachers as this technology can be seen as offering means to support teachers' "transposition" of information [8] and students' "information searches" and "visual analytical reasoning" [9]. That is what is needed also according to [46] and [14].

As demonstrated what happened in the learning activities and the emerging problem spaces, dealt with different dimensions of complexity. This happened even though the teachers had made an "omstilling" of the information and the students' information searches were narrowed down from "Google" searches to material presented with help of the "Vislets". Despite the complexity the data communication technology, the task characteristics and the school children are able to interact quite sufficiently. The results indicate that as long as the students and the technology appear to progress towards a solution of the problem spaces, the complexities in the learning activities offer opportunities for positive, constructive actions. This is in line with [47], who claims that resistance and problem solving are two forces that can create positive challenges for students in order to generate interest and learning.

To be aware of though, is that the data communication and data use with a VA produce changes in human engagement with data and content, and forms and shapes of knowledge [17]. This becomes obvious as the didactic design of the studied classrooms supposes or requests the students to transform their analyses to another modality – into written text. Therefore this study argues that it is not enough to introduce these new requirements associated with technology use and awareness, also new practices of pedagogy have to be adopted at the classroom level as such.

So, by the offered understanding of the learning conditions and the complexity that appeared in the empirical data, its underlined the importance of teacher interaction directed at a) the students' performance – related to awareness of the information processing complexity; b) the subject area – associated with consciousness of the complexity featuring a lack of structure; c) the knowledge content of the students' tasks – linked to attentiveness of the objective task complexity. A special attention is recommended to be at d) aspects of using information, with an emphasis on the construction of meaning from information and not at technicalities, order and procedures in the work – to avoid experience complexity. Maybe the students should be fostered not to, too quickly put the information into a new product [15], [19] Moreover, it is evident There are in this case few possibilities for students' to use the procedures of copying facts from the visualized content as [27] tells about is common for the use of books and web pages and lead just a shallow

knowledge. *To remember is,* visual analyses seem for young students to require time for the construct of understandings. Perhaps this happens with a focus on dialogue, where visual analytical reasoning is centered in the classrooms instead of, or before writing. This demands probably something else than the student centered mode of operation that also [20] highlight and is underlined by [14] as un-problematized.

There seems to be potentials for visual analytics in K12 education. The technology can help teachers to meet the demands to develop students' ability to handle and analyze large amounts of data as [2] puts forward. Much remains to be done though, both to understand how technology for data visualization might enhance learning, understanding and analysis, and to, in classrooms, develop a didactic design including the reasoning processes of students in ways that enhance their ability to deepen their knowledge in order to make well-advised decisions about life and society.

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