A Tool for Dynamic Concept Maps

Master's thesis
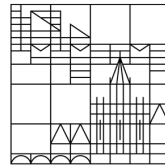
by

Simon Martin

simon.martin@uni-konstanz.de

at the

Universität
Konstanz

Faculty of Sciences
Department of Computer and Information Science

1. Evaluated by: Dr. Barbara Pampel
2. Evaluated by: Prof. Dr. Harald Reiterer

Konstanz, 2023

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Abstract

Concept maps were developed to track and comprehend children's knowledge development (Novak and Musonda, 1991; Novak and Cañas, 2008). Teachers can use concept maps to evaluate their students' understanding (Cañas et al., 2012; Stracke, 2004). By repeating the mapping process with the same mapper, the concept maps can be viewed as one evolving map, known as a dynamic concept map. Dynamic concept maps can be used to assess the current state of knowledge, the learning process and knowledge evolution (Stracke, 2004; Novak and Cañas, 2008). Despite being invented for educational purposes, concept maps are not widely utilized in classrooms despite their numerous advantages (Ley, 2015; Kinchin, 2001).

One reason for that could be the high amount of work a teacher has to invest in using concept maps (Ley, 2015). They have to plan the task, map with students during lessons, collect the maps and evaluate them. This process is especially time-consuming if the teacher wants to use dynamic concept maps. Digital concept mapping can potentially make using concept maps much faster and easier. Following this idea, we created a tool to aid teachers in visual analysis in our previous work (Martin, 2021). To make the process of creating concept maps in lessons as a whole easier for teachers and students, we extended the tool to support the planning, creation and collection of dynamic concept maps. The tool uses a client-server structure to make the planning, mapping and collecting concept maps easier. The tool is created for users without background knowledge. In this work, we give an overview of the applications of concept maps in an educational context. We will provide a summary of the previous work. We will discuss the objective, design and technical application of the tool's extensions. With the help of a small research study, we will demonstrate the tool's usefulness in an educational setting.

1 Introduction

1.1 Motivation

Concept maps are graphical tools for the organisation and representation of knowledge. Novak and Cañas (2008) defined the primary elements of knowledge as *concepts* and relationships between concepts as *propositions*. Novak created concept maps for monitoring the evolution of children's natural science knowledge, as stated by Novak and Musonda (1991); Novak and Cañas (2008). Concept maps have several benefits, including promoting higher-level learning among students and facilitating knowledge assessment by teachers (Cañas et al., 2012; Stracke, 2004). This knowledge assessment can help to adapt the following lessons to the student's state of knowledge. When a mapper repeats the mapping process, the resulting concept maps can be viewed as one evolving map. We refer to a concept map that evolves over time and includes various instances as a *dynamic concept map*. Naturally, using dynamic concept maps, it is possible to assess not only the state of knowledge but also the evolution of knowledge and the process of learning (Stracke, 2004) (Novak and Cañas, 2008). A dynamic concept map naturally holds much more information than a single instance and can bring even more benefits than a non-dynamic concept map. For example, watching one's knowledge evolve can motivate students and aid teachers in evaluating and improving their teaching (Kinchin, 2001).

Although concept maps were invented for an educational purpose and can bring a lot of advantages, they don't find a lot of application in classrooms (Ley, 2015; Kinchin, 2001). One reason could be the high amount of work a teacher invests in using concept maps (Ley, 2015). Creating concept maps during lessons consumes much time, and the evaluation process is also time-intensive. This is especially true for dynamic concept maps since multiple mapping phases are necessary to create dynamic concept maps.

Computer-based mapping can make the application of concept maps a lot more efficient. To make the evaluation process for teachers easier, we implemented a tool that supports the analysis of dynamic concept maps in a previous work (Martin, 2021). Therefore, we interpreted concept maps as a *node-link diagram* where the concepts are interpreted as *vertices* and the propositions are interpreted as *edges*. This way, methods from the field of *graph drawing* can be applied. graph drawing aims to address the problem of constructing geometrical representations of abstract *graphs* and graph-like structures (Battista et al., 1998). These methods can generate a concept placement called *layout*. A good layout should effectively reveal the information in a concept map by applying aesthetic criteria. One criterion, for example, would be that the number of edge crossings should be reduced to a minimum. A good layout can improve the evaluation speed of a concept map significantly (Spener, 2017). We used an algorithm proposed by Spener (2017) to create layouts. This way, the tool can aid in making the dynamic concept for teachers more attractive.

To aid the mapping process during lessons, we extended the tool created in the previous work to simplify the integration into lessons. Thus, we expanded upon the previous analysis by adding a set-up component for planning and organising the creation of dynamic concept maps. We also included a mapping section allowing students to create dynamic concept maps. We evaluated the functions of existing tools in Martin (2021) and give a short breakdown of the results in this work. Most of the tools specifically created for creating concept maps in an educational context don't support options to create dynamic concept maps. The tools that support the creation of dynamic concept maps don't support options to enable the creation of layouts for dynamic concept maps to make the analysis process easier. Exporting the files for the analysis in a different tool isn't possible either since

those tools use specific file formats. Apart from the issues with the files, collecting them manually is a time-consuming process.

Tools that support the option to create dynamic concept maps are designed to create and visualise graphs and networks. The advantage of those tools is that the same tool can be used to create and analyse dynamic concept maps. A downside is that those tools are created for users with background knowledge and provide many functions that aren't necessary for a student to create a concept map. Since a tool's success in an educational context depends on whether the users understand how to use the tool for learning purposes, such tools are hard to apply in an educational context (Rohles, 2021). Another downside is that those tools need a manual collection of files.

We created the tool presented in this work to make the planning, creating and collecting dynamic concept maps easier. An analyser can create a list of concepts and let users create concept maps that represent the knowledge of the mapper at various moments in time. Later, an analyser can analyse the so-created dynamic concept maps and visualise the learning process using the analysis part created in Martin (2021). The tool enables the export of the files in a file format so that the analysis can be done in a different tool. We optimised the tool for the application in an educational context. This is true for the application in the classroom and at home. Mader (2014) mentions that dynamic concept maps could be particularly useful in e-learning. The COVID-19 pandemic has shown a lot of room for improvements in the e-learning field in Germany. If students could visualise their learning successes, it could boost motivation during an e-learning scenario (Sun and Chen, 2016).

We tested the tool as a whole in an educational context. The results presented in this work show that the tool helps students gain a deeper understanding of subjects and helps teachers analyse dynamic concept maps.

1.2 Content

In section 2, we will give some basic definitions. We will define concept maps and introduce concept maps and graphs. Further, we will clarify what makes a good layout. The definition of graphs, dynamic graphs and layouts are based on our previous work, Martin (2021).

We will summarise our previous work in section 3. We will show how the analysis part of the tool works and what ideas were implemented. This is crucial for the setup and mapping to ensure optimal functionality of the tool as a whole. The chapter also summarises the existing tools we analysed in the previous work. We added two additional tools that weren't reviewed in the previous work.

We examined research about concept maps in education to create an optimised tool. section 4 contains the results of this examination. We will provide an overview of how dynamic and non-dynamic concept maps can be used in education. Ruiz-Primo and Shavelson (1996) created the three categories, task format, response format and evaluation format, to simplify the classification of concept maps. These categories influence the final concept maps immensely. We provide an overview of task, response, and evaluation options and select the tool's design based on format advantages and disadvantages.

In section 5, we will give an overview of the presented tool. We will outline the tool's objectives, design decisions, and technical application and provide an example of its use. We tested the tool in an educational environment. Empirical research can be divided into four phases. Following this plan for empirical research, section 6 contains the research interest, the design, the procedure, the results and the research evaluation.

We shall thoroughly analyse the research results in section 7 and contextualise them with the contents of the work. Moreover, we will provide a future outlook.

2 Preliminaries

This section will give some basic definitions necessary for the following chapters.

2.1 Concept Maps

Concept maps are graphical tools for the organisation and representation of knowledge. Novak and Cañas (2008) defined the primary elements of knowledge as concepts and relationships between concepts as propositions. The concepts are usually shown enclosed in boxes of some kind. Connecting lines between two concepts represents the proposition. The text on the lines specifies the type of relation the line represents. A concept is a perceived regularity in events, objects, records of events or objects designated by a label. Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected using linking words or phrases to form a meaningful statement. These are sometimes called semantic units, or units of meaning (Novak and Cañas, 2008). Figure 1, for example, shows a concept map about concept maps. Novak and Cañas (2008) describe the process
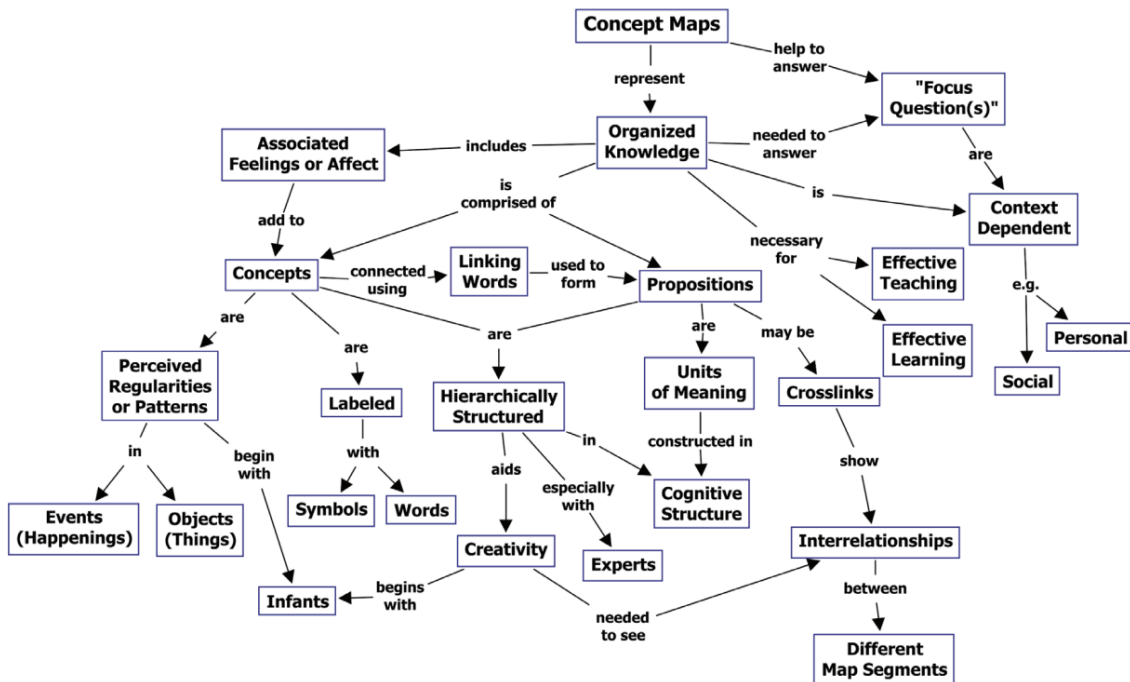
Figure 1 A concept map about concept maps (Novak and Cañas, 2008).

of constructing concept maps as never-ending. From the extraction of the concepts to the creation of the propositions and the positioning of the concepts, constructing a concept map can be an elaborate process that needs many iterations. Novak and Cañas (2008) A final concept map does not only hold information, but also the process of improving a concept map holds information.

To observe this information, it is necessary to have a look at each iteration in the creation of a concept map. A sequence of concept maps that shows the development of a concept map is referred to as a dynamic concept map.

2.2 Graphs

Intuitively, a concept map can be described as points and edges connecting those points. To describe this setup mathematically, the term graph is commonly used. A graph is defined as follows.

A graph $G(V, E)$ consists of the vertex-set V and the edge-set $E \subseteq V \times V$. A graph is *undirected* if an edge is an unordered pair of vertices v and w denoted by (v, w). A graph is called *directed* if an edge is an ordered pair of two vertices v and w denoted by (v, w). A graph is weighted if there is a function $c : E \to \mathbb{R}$ which assigns weights to each edge. A loop is an edge $e = (v, v)$. A path in $G(V, E)$ is a connected sequence of edges $p = e_1, \ldots, e_k$ where $e \in E$ The length of a path $k \in \mathbb{N}$ is the number of edges contained in the path. A path between the nodes v, w is described as the shortest path, if the sum of the weights is less than or equal to all other possible paths between v and w (Tamassia, 2000).

2.3 Dynamic graphs

A sequence of different graphs $G_1, G_2, \ldots, G_n$ where $G_t = (V_t, E_t)$ can be interpreted as an *dynamic graph* which shows the same graph at different times t. There are two common types of dynamic graphs. In a *node-dynamic graph*, the set of vertices V varies with time. In this case, some vertices may be added or removed.

The second type is *edge-dynamic graphs*. In those graphs, the set of edges E varies with time. Some edges may be added or removed between the different times T.

The tool presented in this work only accepts edge-dynamic graphs. Thus, the set of vertices V always stays the same. Only the set of edges E_t changes with the time t (Harary and Gupta, 1997).

2.4 Layouts for non-dynamic graphs

A graph representation aims to reveal the information contained in the graph effectively. To aid this goal, the central task is to choose an appropriate form of representation. To reach this, we have to map the elements of the graph to visual features in the visual space. The graph layout is part of the mapping concerned with topological and geometric
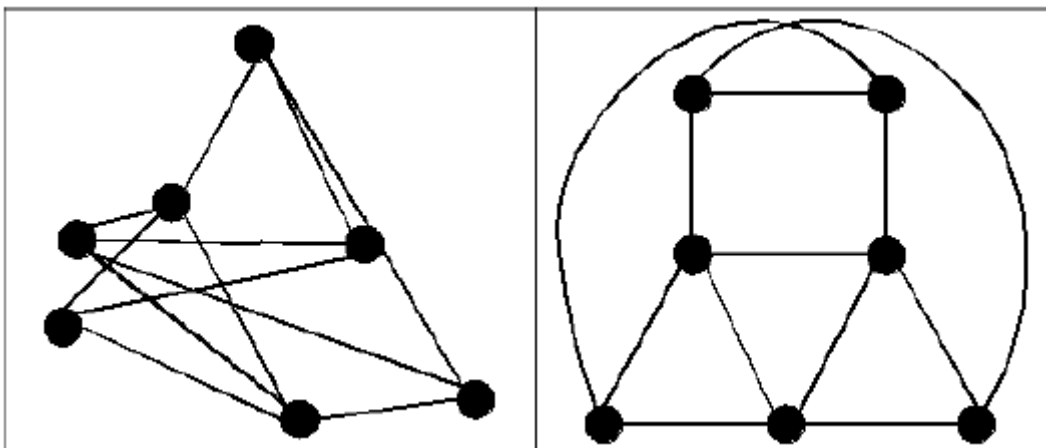
Figure 2 The difference between poorly (left) and a well (right) layout graph (Bennett et al., 2007).

properties (Mader, 2014).

A graph can be visualized by a matrix or list where the neighbourhood of each node is shown. The most common visualization of a graph is the node-link diagram, in which vertices are shown as points described through a single position, and edges are depicted as lines linking their endpoints.

For this work, we will focus on the node-link diagram to be more accurate on a *straight-line representation* of the link-node diagram. The straight-line representation allows edges only to be shown as a straight line, so the positioning of each edge is entirely determined by their start and end points.

It is easy to create a readable representation for graphs with only a few nodes and edges. In this case, the vertices could be randomly spread in a frame and still readable in most cases. But the larger the graph gets, the harder it becomes to keep the layout visually pleasing and readable. Bennett et al. (2007) divide the aesthetic problems into two domains, the syntactic and the semantic problem. The syntactic problems are to avoid occlusion with overlapping edges and vertices. The semantic problems highlight underlying characteristics of the underlying data model and are influenced by the task the data is used for (Bennett et al., 2007). The tool is mainly concerned with the syntactic part of the visualization. Bennett et al. (2007) defined some aesthetic criteria for graph visualization.

- Vertices have distinct positions.

- All edges should have about the same length.

- Vertices should be distributed well over the drawing area.

- The number of edge crossings should be kept small.

- Symmetries in the graph structure should be visible in the visualization.

Figure 2 shows the node-link diagram representation of a graph. The representation on the left is much harder to read than the representation on the right, where the aesthetic criteria were applied (Bennett et al., 2007).

2.5 Layouts for dynamic graphs

In addition to the previously mentioned aesthetic criteria, there comes a new challenge when looking at dynamic graphs: presenting a graph so that the evolution of the graph is easy to read. It should be possible for the user to maintain a cognitive model of the graph as it changes over time, referred to as the mental map in literature. Figure 3 shows how adding two edges can destroy the mental map, even though the three individual drawings of the graph are aesthetically pleasing (Mader, 2014). It is clear where each vertex is located in the graph when the nodes are moved as little as possible to maintain stability. This is the simplest way to maintain the mental map, but it sacrifices the aesthetic quality of each visualization. Figure 4 shows three instances of a graph. The vertices stay at the same positions, and the same edges as in Figure 3 are added and removed. Adding the edges reduces the aesthetic quality of the graphs in this example.

To preserve the mental map, three criteria should be observed:

- When repositioning nodes, the order of nodes should stay consistent in both the horizontal and vertical directions.

- Proximity relations require nodes to be equidistant to each other.

- The dual graph should be maintained (Diehl and Görg, 2003).

As we have seen in the two examples, a trade-off exists between quality and stability. The optimal layout for a dynamic graph should have good individual quality and allow the viewer to preserve a mental map.
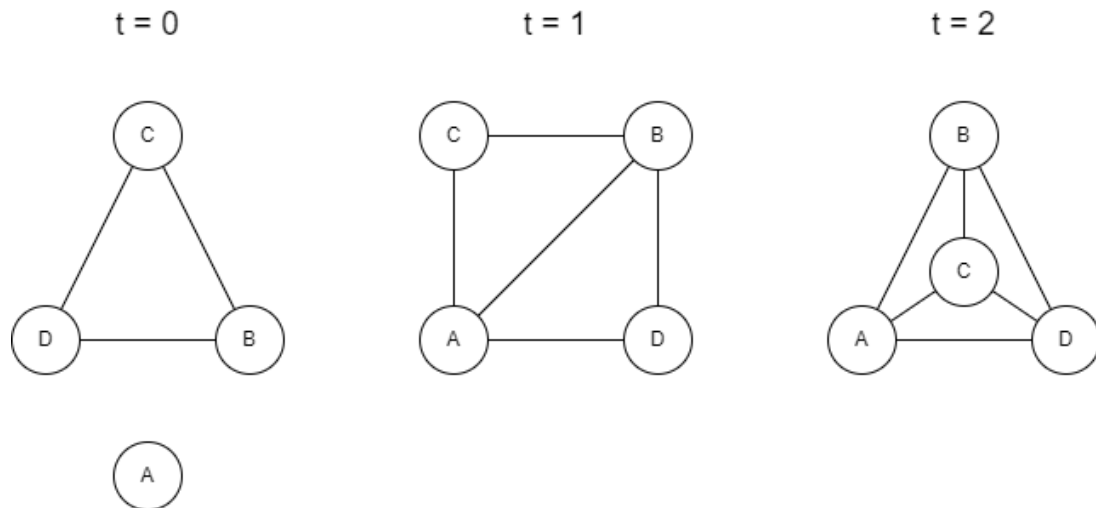
Figure 3 Moving the vertices can destroy the mental map.
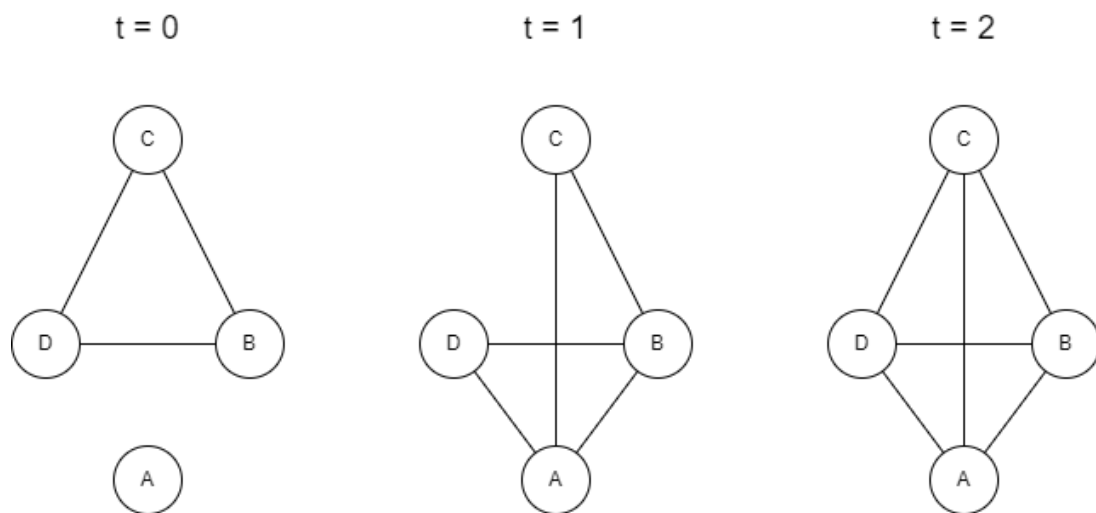
Figure 4 Just adding edges can destroy the aesthetic.

3 Previous work

In previous work, Martin (2021), we created a tool to visualise dynamic concept maps. Since the developed tool is a part of the tool presented and evaluated in this work, we will refer to the tool created in the previous work as the "analysis part". In this chapter, we will give a short summary of the results of this previous work.

3.1 Method

Good layouts, as shown in section 2, can be challenging. Therefore, we applied some methods from the *graph drawing* field. Graph drawing addresses the problem of constructing geometrical representations of abstract graphs and graph-like structures (Battista et al., 1998). We will give a short explanation of how the used method works and can be derived. Therefore, we will show graph drawing methods for non-dynamic graphs and explain the method used for dynamic graphs based on that explanation. The in-depth explanations can be found in Martin (2021).

3.1.1 Method for non-dynamic graphs

Force-directed methods are a common way to draw graphs. Steel rings represent vertices, and springs represent edges. The system includes attractive and repulsive forces, and over time, the steel rings will move until the springs are unloaded as much as possible, and energy is minimized. Figure 5 shows a schematic representation of this system. If the natural length of the springs represents the optimal length, we should end with a quite optimal representation. It is possible to track the energy of the whole system by adding the remaining energy in the springs. Intuitively, the layout is more pleasing the lower the remaining energy is. The simplest way to lower the energy is to move the vertices iteratively according to the partial derivates of the energy function (Mader, 2014). This method is also known as "spring embedders".
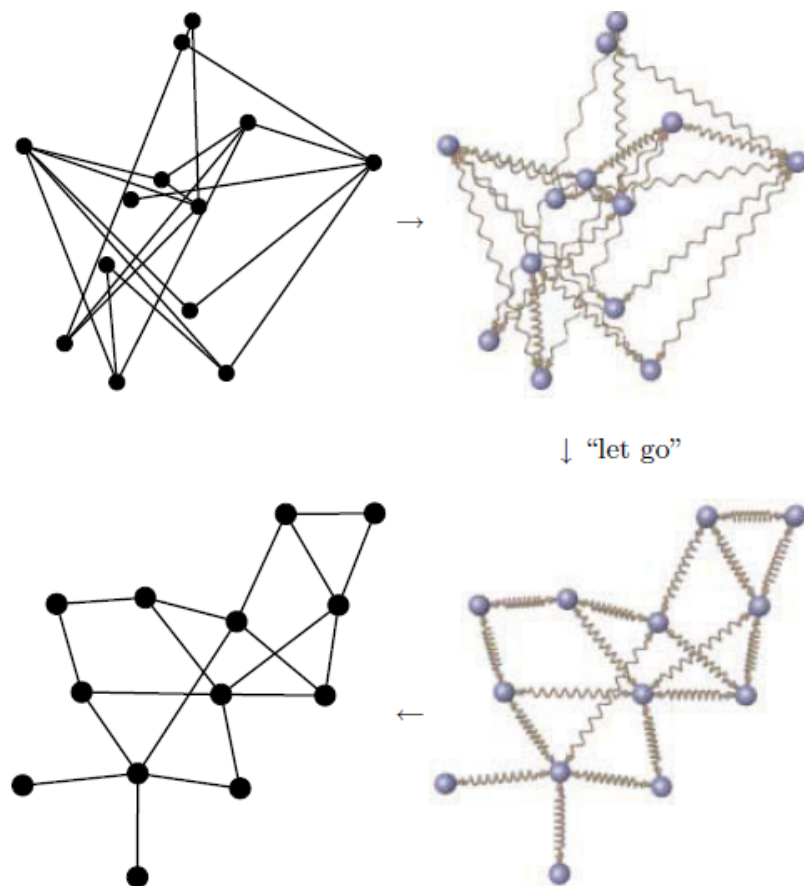
Figure 5 Spring embedders (Brandes, 2001).

The idea of the energy was adopted in the context of *Multi-dimensional scaling*. Multi-dimensional scaling is a way to visually represent the structure of a group of objects by using data that estimates the distances between each pair of objects. The data may include similarities, dissimilarities, and distances (Mader, 2014). Instead of energy, we call the pressure in the system stress. So, for all nodes, we can calculate a dissimilarity value to each other. We can utilize the shortest path distance between each vertex as dissimilarities for the layout of a graph in a two-dimensional space. If no paths between the two vertices exist, the distance is infinite. We can calculate the stress by summing up the differences between the distances of each vertex to each other and the distances and theoretical dissimilarities we stored (Mader, 2014).

When the stress is reduced to a minimum, two neighbouring vertices have the shortest

path distance of one. Therefore, they are placed close to each other. Vertices with a longer shortest path distance are naturally placed further away from each other based on their theoretical dissimilarities. This way, the graph is spread across the whole area. Symmetries in the Graph structure should be represented by the shortest path distances of the edges (Mader, 2014). Nodes with many neighbouring nodes are pushed to the centre, and nodes with fewer neighbours are pushed to the sides. The easiest way to minimize stress is by using a majorization method. This involves finding a function greater than or equal to the given function. However, Gansner et al. (2004) used a localised variant of a majorisation similar to the optimisation process of the spring embedders. In each optimisation cycle, we iterate over each vertex. Each other vertex votes for a vertex placement of the selected one based on the positions. All the votes combined result in the new position of the selected vertex. With this reduction, the stress in the layout gets reduced with each iteration. Pseudo-code for the algorithm is shown in algorithm 1.

Algorithm 1: Minimisation process(Mader, 2014).

Input: Undirected, connected graph $G = (V; E)$,
  initial positioning $P = (p_i), i \in V$
  dissimilarity matrix $D = (\delta_{i,j}), i, j \in V, t$ (the shortest path distance)
Output: Positions P at a local minimum of $\text{stress}(P)$
$W \leftarrow (\omega_{i,j}) = (\delta^{-2})$
while p *or stress(P) change by less than ϵ* **do**
  for $i \in V$ **do**
  $$p_i \leftarrow p_i \frac{\sum\limits_{j \neq i} \omega_{i,j}(p_j + s_{i,j}(p_i - p_j))}{\sum\limits_{j \neq i} \omega_{i,j}}, \text{with } s_{i,j} = \begin{cases} \frac{\delta_{i,j}}{||i - p_j||}, & \text{if } ||i - p_j|| > 0 \\ 0 & \text{otherwise} \end{cases}$$
  end
end

3.1.2 Method for dynamic graphs

The method shown in the previous chapter can help to create good layouts. To keep the aesthetic quality of each individual graph high and build a dynamic graph, which can preserve a mental map, the earlier presented algorithm 1 has to be modified so that the stability can be factored in. To do this, we can add additional forces.

The main idea of anchoring is to minimise the distance to a reference layout. To minimise the distance, each vertex is pulled to its counterpart in the reference layout in addition to the forces among the nodes in one layout. Figure 6 shows a schematic representation of the pulling strings between the different instances of the concept map and the reference layout. The tool allows manually creating an anchor positioning for the graph. This allows skilled concept mappers to create their expert layout and map it onto all graph instances. Mader (2014) proposes using a layout created to use the aggregation of the layouts as an anchor or to use the aggregation of the preceded layouts as an anchor. The quality of the result is dependent on two factors. First, the quality of the anchor positioning and second, how much it is factored in. If a teacher creates the expert map, the anchoring method can help the teacher to compare the maps from multiple students more easily.

The main idea of the linking approach is to use all information about the layout at different
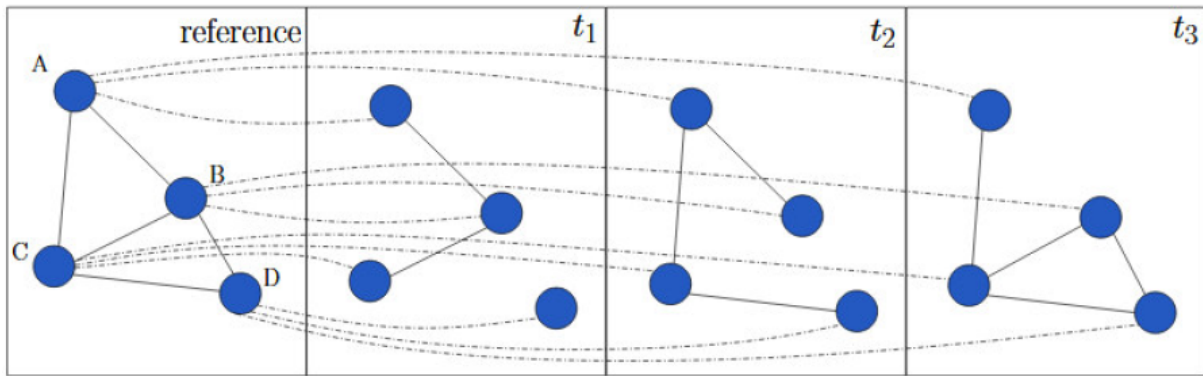
Figure 6 Schematic visualisation of the anchoring layout algorithm (Archambault, 2012).

times for the layout at one time. In contrast to the anchoring method, it isn't possible to calculate the layout one after another. We can image strings pulling between the same node in different instances. Figure 7 shows the schematic representation of those strings. It's
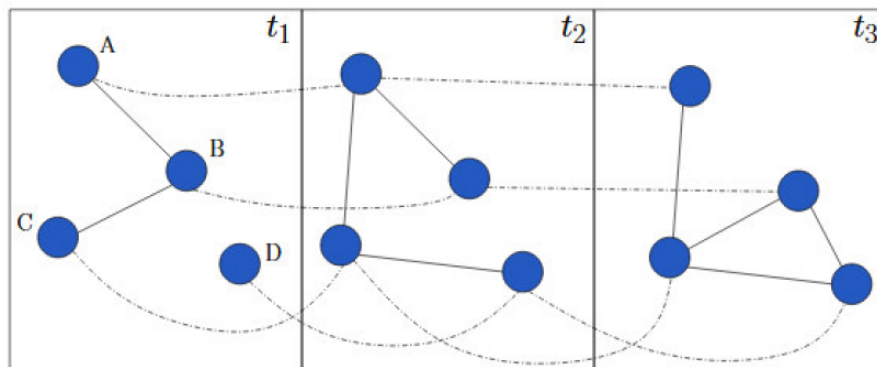
Figure 7 Schematic visualisation of the linking layout algorithm(Archambault, 2012).

hard for the anchoring version to beat the visualization quality if the positioning knowledge over the entire period is used for the layouts (Mader, 2014). Therefore, the linking version could be applicable in an educational context to compare the different instances of a dynamic concept map. The downside of the linking version is that comparing different dynamic concept maps is difficult since there is no stability between the layouts of the different dynamic concept maps. The option to set the anchor makes comparing different maps much easier. So, each of the two versions has advantages and disadvantages. Spener (2017) presented a mixed version that combines linking and anchoring. The influence of the linking and anchoring versions can now be controlled in this version. So, it is possible to control the trade-off between quality and stability and the trade-off between linking and anchoring to either emphasise the option to compare different instances of a dynamic graph or different concept maps. This can be implemented with an adjusted version of algorithm 1, shown in algorithm 2.

Algorithm 2: Minimisation process from Martin (2021)

Input: connected graph $G^t = (V, E)$ at all times T
initial positioning $P = (p_i^{(t)}), i \in V, t \in T$
dissimilarity matrix $D = (\delta_{i,j}^t), i, j \in V, t \in T$ (the shortest path distance)
reference layout $P^{(r)} = (p_i^{(r)})_{i \in V}$
quality-stability-factor $\alpha, 0 \le \alpha, \le 1$
linking-anchoring-factor $\beta, 0 \le \beta, \le 1$
Weight $W = \omega_{i,j}^t, W \in \{D - 1, D^{-2}\}$

Output: Positions P at a local minimum of $\text{stress}_{\alpha,\beta}^{Mi}(P)$

while $\text{stress}_{\alpha,\beta}^{Mi}(P)$ *changes by less than ϵ* **do**

  for $t \in T$ **do**

    for $v \in V$ **do**

      $p_i' = (0, 0)$

$$p_i' \leftarrow p_i' + \alpha \times \left(\frac{\sum\limits_{j \neq i} \omega_{i,j}^{(t)}(p_j^{(t)} + s_{i,j}(p_i^{(t)} - p_j^{(t)}))}{\sum\limits_{j \neq i} \omega_{i,j}^{(t)}} \right)$$

$$\text{,with } s_{i,j} = \begin{cases} \frac{\delta_{i,j}^{(t)}}{||p_i^{(t)} - p_j^{(t)}||}, & \text{if } ||p_i^{(t)} - p_j^{(t)}|| > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$p_i' \leftarrow p_i' + (1 - \alpha) \times \beta \times p_i^{(r)}$$

$$p_i' \leftarrow p_i' + (1 - \alpha) \times (1 - \beta) \times \left(\sum_{\substack{t'=1 \\ t' \neq t}}^{T} \zeta(t, t') p_i^{(t')} \right)$$

$$p_i^{(t)} \leftarrow p_i'$$

    end

  end

end

3.2 Tools for concept map visualisation

In the previous work, we compared different tools for visualising concept maps. Therefore, we examine existing tools under these three aspects to see if they can help visually analyse dynamic concept maps in an educational context. We examine those tools under three aspects:

- Does the tool support an option for automatically constructing a layout?
- Does the tool support an option for constructing dynamic concept maps?
- Does the tool support an option for automatically constructing a layout for dynamic concept maps that preserves a mental map?
- How difficult is the tool for a user without background knowledge?

We looked at tools created specifically for creating and visualising concept maps like *Cmap*, *MaNet* and *Lucidchart*. MaNet (Manheimer Network Elaboration Technik) is an advanced

version of Net software. It was not mentioned in Martin (2021). It is often used in German research papers as it provides two options for analyzing concept maps. However, support for MaNet has been discontinued since 2015. The tools all support some options for layout generation. Cmap is particularly useful for organizing and acquiring knowledge and includes an "auto-layout" feature with hierarchical and force-based layout algorithms. Figure 8 shows the difference between a force-based and hierarchical layout graph using Cmap. It also features an automated layout function, which only supports hierarchical and not force-based drawing methods. Visualizing a concept map using Lucidchart's hierarchical layout method may not be especially readable if the data is not hierarchical. For instance, the graph shown in Figure 9 may not be easy to read.

 Only Cmap has an option to view the creation history of the concept maps. This feature
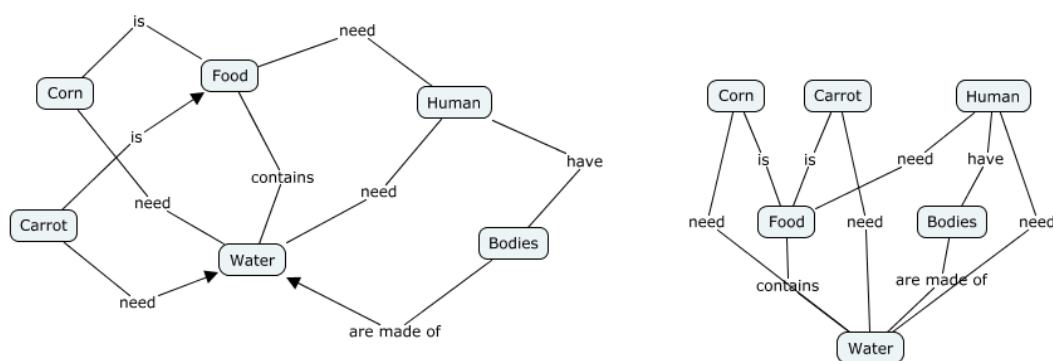
Figure 8 Two alternative drawings of a concept map using Cmap. The right one has a hierarchical layout algorithm, and the left one with force-directed.

allows users to go back to older states of the map to observe their learning. The visualization process of concept maps may not always clearly preserve the mental map Since no algorithmic support for creating a specific layout for the history is given. MaNet includes an option to open multiple concept maps side by side and position all concepts according to an anchor layout. This feature can be used to improve the analysis of dynamic concept maps. *Diagrams.net* is a browser application supporting the creation of various diagrams and graphs. This tool creates UML and user-interaction diagrams, as well as concept maps. It offers auto-layout methods like Flow, hierarchical, tree-like, circular layouts, and an organic layout option using a force-based layout. Users can create custom layouts with the JGraph library. Diagrams.net also supports a feature called layers. With this feature, the user can create a collection of diagrams. Using this feature, it is possible to show a dynamic concept map without preserving a mental map. It is not possible to use a dynamic layout method. This tool supports many different functions and isn't easy for users without practice.

We also looked at mind mapping tools since you may find recommendations for *MindMeister*, *Ayoa*, or *Whimsical* when looking for concept mapping tools. However, these tools have a preset layout and don't allow circular map structures. Similar options include *MindManager*, *Popplet*, *MindNode*, and *Mindomo*.

The last category of tools we looked at are tools designed to visualize graphs or other networks like *Visone*, *YEd* and *Cytoscape*. Cytoscape is a tool for visualizing complex networks and wasn't viewed in Martin (2021). Those tools for graph visualization are very powerful tools with many options that are hard to use for people without any background
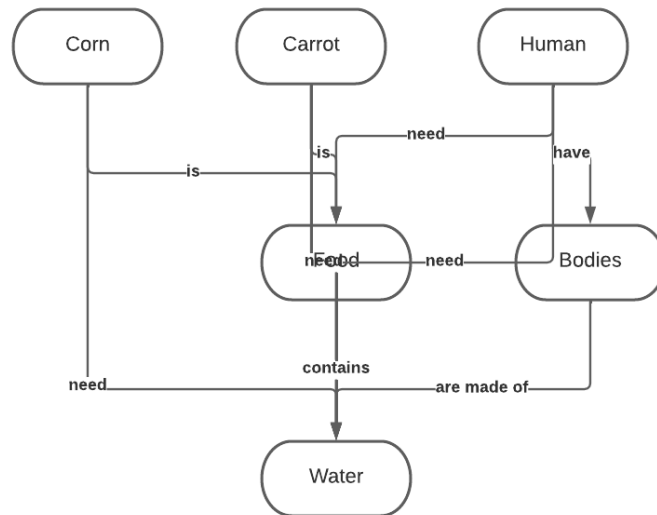
Figure 9 The drawing of a concept map using Lucidchart's auto layout option.

knowledge. Those tools support many layout methods. Among other things, YEd supports layout methods called Organic-layout and Hierarchical-layout. The Organic-layout is a variation of the force-based method introduced earlier. When using one of the methods, YEd gives the user many controls to refine the visualization. This wide variety of options is impossible to use without understanding graph drawing methods. YEd also supports a feature called One-click-layout. This feature provides users without background knowledge a way to use the tool. It tries to use the most fitting type of layout. Visone supports a wide variety of different layout methods. Visone has different layout options, including stress minimisation. Users can customize their layouts with various controls. It also has a quick-layout option for beginners. The quick-layout option doesn't work for dynamic concept maps. Cytoscape supports the layout generation of graphs using force-based and other methods.
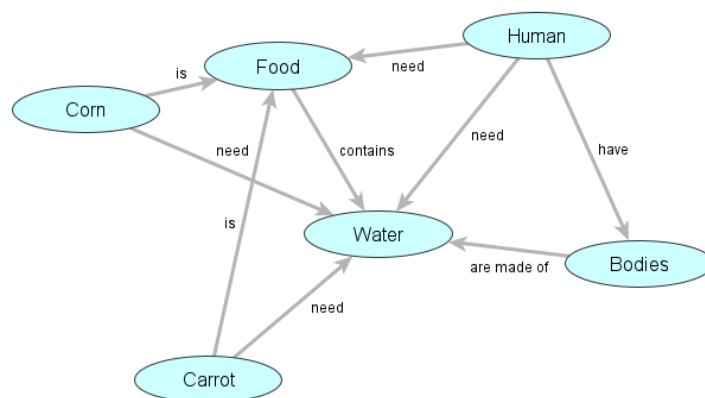
Figure 10 Drawing of a concept map using the stress minimisation option of Visone.

YEd only supports static graph visualization. The other two tools support the visualisation of dynamic graphs. In Visone, the individual maps can be added to a collection. After creating the collection, the user can use three visualization algorithms for dynamic graphs. The tool supports the anchoring and linking method.

For all three options, the user can choose an edge length. For the linking and the anchor-

ing layout, the tool gives the additional option to set the factor to control the quality and stability. Visone also supports a mixed version. Overall, Visone supports a similar set of functions as the analysis part.

Cytoscape provides an App Store with extensions. Using the *DyNetViewer* extension, it is possible to create layouts for dynamic graphs. The tool is difficult to use since the libraries have to be added in the first place, and the tool supports a lot of functions.

Tool	Auto-layout option	Dynamic concept maps	dynamic Auto-layout option	Difficulty
Cmap	Force-based, hierarchical	Creation history	-	Moderate
MaNet	-	separate maps	static layout side by side	Moderate
Lucidchart	Hierarchical	-	-	Easy
Mind mapping tools	-	-	-	Easy
Diagrams.net	Force-based and other	Yes	-	Difficult
YEd	Force-based and other	-	-	Difficult
Visone	Force-based and other	Yes	Yes	Difficult
Cityscape	Force-based and other	Yes	Yes	Difficult

Figure 11 The features each tool provides.

3.3 Implementation

The analysis part aims to generate dynamic concept map layouts to maximize information gathering. This process should be as fast and easy as possible.

It was important that the analysis part provides an option to open existing files. The user should be able to change between the different instances of a dynamic concept map.

In addition, the tool should provide some control options regarding the visualization. Spener (2017) has shown in his work that selecting the right layout algorithm can significantly influence the quality of the visualization.

The main application of the tool was set in an educational context. Therefore, it was clear users usually don't carry any background knowledge about graph drawing methods. Because of this, it was important that the tool provides no unnecessary controls. On the other hand, it was important that the visualizations of the dynamic concept map are as beneficial as possible to make analysing the concept maps easier. Two requirements must be considered. Firstly, each concept map must meet high-quality standards and adhere to

the aesthetic criteria for graph drawing that have been previously defined. Secondly, it is crucial for the user to maintain a mental map while switching between different instances of visualizations. Considering the trade-off between these two requirements, the tool should provide enough options for the user to strike the perfect balance between individual quality and overall stability.

The tool supports the visual analysis of dynamic concept maps. The downside of visual analysis of maps is that it can be very time-intensive. We use the mixed layout algorithm to make this process for the analyser faster and easier. The layout can make analysing the maps much easier for the analyser. Spener (2017) has shown that the linking layout can improve the analysis speed between different instances of a dynamic concept map. The anchoring layout can improve the analysis speed between maps from different mappers. The mixed version has the advantage that both aspects can be used. Therefore, the analysis tool uses algorithm 2.

The analyser can set the scaling factors between the quality and the stability and the scaling factor between the linking and the anchoring version. This way, the analyser can create the best layout for the intended purpose. If it is more important for the analyser to compare dynamic concept maps from different mappers, the analyser can use a higher factor of anchoring, and if it is more important for the analyser to compare different instances of the same map, the analyser can use a higher factor of linking. The mapper can also influence the factor between quality and stability to find the perfect trade between quality and stability the analyser wants. For the anchoring part, the user can set the anchor positioning manually. The threshold when the search for the minimal energy terminates can't be manipulated manually. The desired length of the edges isn't controlled manually and is set to a fixed value. This leads to more consistent-looking concept maps.

When the user changes between different instances of the concept map, it is animated to improve the mental map's preservation further. The analysis part was developed with Python. Therefore, the analysis part must be installed on a PC before use.

3.4 Evaluation

We tested the tool's usability with a quantitative research approach based on the "System Usability Scale". The analysis part was tested with students of computer science and other subjects alike. The research results have shown that the analysis part is usable for analysers with basic knowledge about layout algorithms and analysers without it. Overall, the quantitative research results paint a positive picture regarding the tool's usability. The results of some open questions backed this. However, the results have to be proven in an educational environment.

4 Concept Maps in an educational context

Concept maps were developed to help track and comprehend children's evolving knowledge of natural science (Novak and Musonda, 1991; Novak and Cañas, 2008). Since the creation of concept maps by Novak and Cañas (2008), their applications have increased. Research has always focused on the application in an educational context.

In this chapter, we will give an overview of the applications of concept maps in an educational context. Ruiz-Primo and Shavelson (1996) created the three categories, *task format*, *response format* and *evaluation format*, to make the description of the creation of a concept map easier. We will review the categories and classify the concept maps that were created using the tool provided in this work. Afterwards, we will examine the role of the teacher in successfully applying concept maps in an educational context.

4.1 Applications

Today, more than ever, it is important that people succeed in acquiring, structuring, communicating and applying knowledge (Mandl and Fischer, 2000). The concept map has been described as the most important tool in science education today (Mandl and Fischer, 2000). Concept maps can provide support with these tasks in different scenarios in an educational context (Mandl and Fischer, 2000). It can be used for organisation, teaching, learning and diagnostic purposes.

When the concept mapping method is used, it can always fulfil multiple purposes. The creation can be part of the teaching but can later be used to support the learning collaboratively or alone. In addition, the teacher can still analyse the maps and give the students feedback.

4.1.1 Organizing tool

Stracke (2004) proposes the usage for constructing lessons and curricula. Important key components like lessons, thematic blocks, key skills and others can be identified and integrated into a concept map. A graphical representation containing the links between themes and grade levels can help structure the contents. In this manner, concept maps can improve a discussion about the curriculum. The same is true for the planning of the contents of a year or the planning of one lesson.

4.1.2 Teaching tool

Stracke (2004) also proposes the usage as a teaching strategy. When we look at concept mapping as a teaching strategy, the focus lies on the concept acquisition (Mandl and Fischer, 2000). Concept maps can be used as an "Advanced Organizer" for the student (Stracke, 2004). An Advanced Organizer visually connects students' previous knowledge to new information at the start of a subject. It serves as a guide for the topics covered in the subject.

Another application would be as a tool for brainstorming (Stracke, 2004). First, terms associated with the subject are collected. Afterwards, they are ordered and connected. Another application in a teaching context is the summary of units and the consolidation of knowledge. Concept maps can help to emphasize important connections between subjects. Concept maps are simpler than text summaries (Stracke, 2004).

4.1.3 Learning tool

Stracke (2004) also proposes the usage of concept maps as a learning tool. Bloom (1956) created the "Taxonomy of Educational Objectives: The Classification of Educational Goals" as one of the earliest efforts to show the relationship between learning and assessment. The taxonomy identified six test items that demanded progressively higher cognitive skills from the learner. Cañas et al. (2012) states that learning at schools often stays at the first level, but it is a key task for educators to enable a higher level and more meaningful learning. The other levels of Bloom's taxonomy are (2) comprehension, (3) application, (4) analysis, (5) synthesis and (6) evaluation (Cañas et al., 2012). Novak and Cañas (2008) mention the difference between rote and meaningful learning. He describes three conditions that have to be met to enable meaningful learning:

a) To ensure effective learning, information should be presented using clear language and relevant examples. Concept maps can aid teachers in identifying student's prior knowledge and guide the sequencing of learning tasks. This approach gradually builds on the student's existing understanding, allowing them to develop more explicit knowledge and create conceptual frameworks to anchor their learning.

b) To learn, it is necessary for the individual to have relevant prior knowledge.

c) As a learner, it is important to choose to learn meaningfully. While teachers and mentors can only indirectly control students' motivation to learn in this way, they can influence this choice through their instructional and evaluation strategies. In particular, instructional strategies that connect new information to the learner's existing knowledge can promote meaningful learning.

Concept maps facilitate higher-level learning by emphasizing the relationships between concepts. When creating a concept map, students are encouraged to consider the connections between subject-related information (Bruhn et al., 2000). The application of concept mapping can support the active process of structuring knowledge (Novak and Musonda, 1991).

Concept mapping doesn't have to be a solitary activity in which learning occurs with little guidance (Kinchin, 2014). Concept mapping can be included in lessons beneficially.

Dialogues during cooperative mapping activity can help to improve learning. The dialogue between students can help, as well as the feedback from a teacher. According to Kinchin (2014), concept maps that include feedback have a greater impact on improving student performance. Novak and Cañas (2008) have highlighted the importance of scaffolding student's learning. In this context, Mandl and Fischer (2000) mention concept maps as a tool for cooperative learning. Two or more students can use a mapping space to visualise a shared problem room that can help them structure information. This can be especially useful in complex learning environments and when students aren't face to face (Mandl and Fischer, 2000). Following the coronavirus crisis, exchanging ideas in an online scenario has become increasingly important. The mapping in groups can also improve the communication style about subject-related information(Bruhn et al., 2000).

4.1.4 Diagnostic tool

Concept maps can also be a diagnostic tool for students learning (Stracke, 2004). The idea is that with the graphic representation of subject-related content in the form of concept maps, the mapper's state of knowledge can be concluded. Within the analysis of concept maps, it is possible to find missing conceptions or misconceptions in the relations between concepts.

The map analyst doesn't have to be a teacher. Anyone can analyze their own concept maps for self-diagnostic purposes. Pankratius (1990) mentions in his work that learners can get a positive perception of teaching when they see their learning advancement. Concept maps can help a teacher get an overview of the performance level of a study group (Stracke, 2004).

The application can differ in different situations. Concept mapping can be used during a lesson to assess a class's prior knowledge at the beginning of a unit. Concept mapping can also be used for an intermediate diagnosis during a unit. In these two cases, the teacher can adjust the further orientation of the lesson according to the results. Concept mapping can also be used at the end of a unit as a tool for the performance measurement of the students (Ley, 2015).

A dynamic concept map can be used to assess the evolution of knowledge and the process of learning (Stracke, 2004) (Novak and Cañas, 2008). This can help teachers evaluate their teaching since the teacher sees which methods support a deeper understanding of information and which do not (Kinchin, 2001). True-false or multiple-choice questions are commonly used in schools to test existing knowledge. This often limits performance measurement to the first level of Bloom's taxonomy (Bloom, 1956). This way, the learner focuses primarily on the memorisation of information. According to Novak and Cañas (2008), the worst forms of objective tests are short-answers tests. These tests require verbatim recall of statements, which may be impeded by meaningful learning. For meaningful learning, new knowledge has to be assimilated into existing frameworks, making it difficult to recall specific, verbatim definitions or descriptions. The challenge for educators is to design instructions and tasks that encourage students to think critically and creatively (Cañas et al., 2012). Using dynamic concept maps to assess knowledge can lead to a deeper understanding of learning and encourage the learners to go deeper than just memorising information (Cañas et al., 2012). This way, using concept maps as a diagnostic tool can encourage meaningful learning (Novak and Cañas, 2008).

4.2 Task format

Different concept mapping tasks lead to the formation of different mental representations (Kinchin, 2014). Choosing the right task is important to analyse a student's understanding of a specific topic. The fact that different conditions lead to different maps is an aspect that educators must consider carefully (Cañas et al., 2012). Therefore, instructors should know what they want to accomplish with their task (Kinchin, 2014).

The nature of a concrete mapping task can differ greatly. Figure 12 shows the restrictiveness of different task formats. Starting with a blank sheet of paper, the mapper has complete creative freedom over the map's content. Such a task is called a "Construct-a-map task". This freedom can be reduced if the mapper starts with parts of the final concept map. Cañas et al. (2012) extended the framework shown in Figure 12 into a two-dimensional framework, covering freedom of content and structure. Figure 13 shows the different tasks positioned in the framework. Learners are given extensive control at

Degree of Directedness

Figure 12 The degree of directedness of different tasks (Ruiz-Primo, 2000)

the high end of the freedom continuum. The mappers define topics, terms, and structures. (Cañas et al., 2012) In the middle areas of the framework, the mappers are usually provided with parts of the concept maps. These tasks can include, for example:

- **A focus question** is the main inquiry that a mapper seeks to address. A well-crafted focus question improves the quality of resulting concept maps. A focus question impacts both content and structural aspects. Using a focus question can lead to the construction of more explanatory maps (Rohles, 2021).

- **A root concept** serves as the foundation of a concept map, greatly impacting its structure. Providing a root concept map can strongly affect the resulting concept map. A root concept is even more likely to result in more explanatory concept maps than a focus question (Cañas et al., 2012).

- **A list of concepts** and/or links that learners should include in their maps.
  One of the instructor's most commonly used tasks is providing students with a list of concepts but allowing them to add additional ones. A key aspect that leads to learning while constructing a map is the process of building the propositions (Cañas et al., 2012). Students construct better maps when given a list of concepts than maps constructed without conditions or a text containing the concepts (Cañas et al., 2012). Without a list of concepts, the maps can tend to have a star-like structure. Concept maps tend to have more cross-connections when providing a list of concepts. Mappers are often intimidated by the blank space and struggle with constructing a concept map (Cañas et al., 2012). A list of concepts can help to deal with this problem.
  This restrictiveness can be reduced if the task allows for additional concepts and the list is viewed more as a suggestion. The downside is that not every concept is part of the final map. Important concepts can be overlooked. A more restricted variant of this task is to allow only the usage of the concept provided for use in their concept map. This leads to a stronger restriction of content and structure (Cañas et al., 2012). This task can determine a student's knowledge (Cañas et al., 2012).

- **A Skeleton maps** is a concept map with only central concepts and links.
  When dealing with complex subjects, utilizing a structured outline created by an expert can serve as a viable option. An expert skeleton map is a starting point for the mapper, containing only a few expert-selected concepts. This task is frequently

used in conjunction with a concept list (Cañas et al., 2004). It limits both the flexibility of content and structure. This method is quite work-intensive to prepare since a good skeleton map is key to improving the maps of the mappers. This can be quite challenging and time-intensive since it is much more difficult to build a good map as a skeleton for further mapping with only a few concepts (Novak and Cañas, 2008) rather than building a whole map.

- **An empty concept map** that has to be filled. This approach allows students to use expert concept maps with empty cells instead of building their own. A task to fill in the gaps in an already constructed concept map leaves little freedom (Kinchin, 2014). Such a task is called "fill-in-the-map task". This method can encourage root learning but doesn't represent much knowledge of the mapper since the mapper has no freedom in the map's structure. If a list of concepts is given, the mapper has no freedom in the content either (Cañas et al., 2012).
- **A finished map** can also be provided. The task with the least freedom is to observe a finished map. This task can be used to activate students (Stracke, 2004). This task serves as a teaching tool to demonstrate subject structure.

Some of the provided elements can be combined. Mapping under no condition usually leads
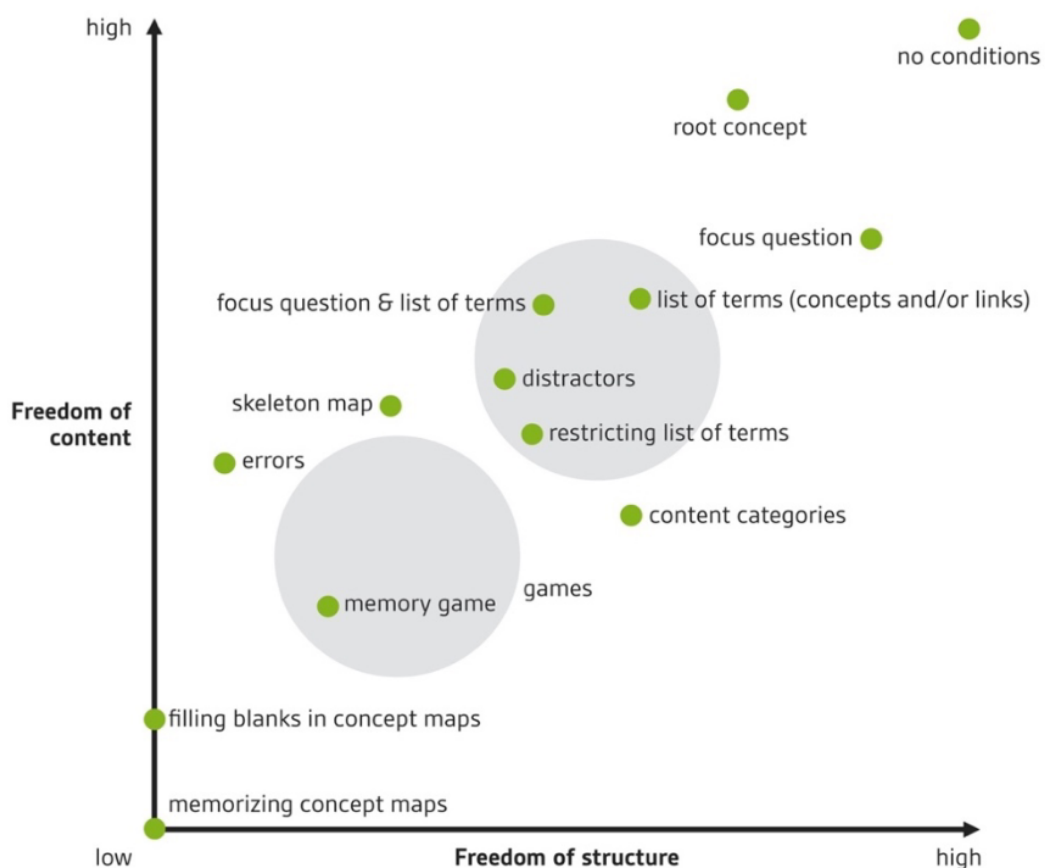

Figure 13 The degree of freedom of different tasks (Rohles, 2021).

to a descriptive concept map instead of an explanatory map. Construct-a-map tasks can reveal the conceptual understanding better but are more challenging than fill-in-the-map tasks (Rohles, 2021). Some of the tasks can be combined or performed one after another,

giving the mapper more and more freedom. Additional directions can change the basic tasks (Stracke, 2004). One example would be to allow only hierarchical maps. A task like this could make sense if the structure of the subject itself has a hierarchical nature. Another option would be to think of linking words when connecting two concepts but omitting them in the map. The more freedom mappers have, the more a map can potentially represent the knowledge of a mapper. Maps take multiple iterations to become explanatory and accurately represent the mapper's knowledge. As a result, this process takes a lot of time. Creating more detailed directions can result in the production of more explanatory concept maps with fewer iterations needed. According to Krabbe (2014), task formats that are highly structured are more likely to prompt students to access their existing knowledge rather than simply displaying it. Although the maps represent the mapper's knowledge, the structure and content may differ. According to Moon et al. (2010) condition, where students have little freedom to express their knowledge structure, teachers are most likely to misinterpret the student's knowledge structure. The more conditions given for a task, the easier the mapping process becomes. However, more conditions lead to less knowledge about the mapper and make interpretation difficult.

This work utilized a task format requiring students to construct their maps. The students are provided with a restrictive list of concepts. The students are meant to think of linking phrases but omit them in the map. This approach allowed us to evaluate knowledge development and the learning process. The concept maps created can aid in the deeper understanding of the subject matter for those who use them.

4.3 Response format

For instructional purposes, maps can be drawn using pencil and paper. A huge problem with this method is that it is hard to revise the maps. The attempts to revise a concept map like this can make the map convoluted (Stracke, 2004). But often only after several modifications, additions and subtractions of concepts and propositions a concept map become good (Novak and Cañas, 2008). This method can be expanded, making the revision easier using post-its as nodes. The post-its can be moved freely, and their position is fixed in the end. At some point, the position has to be fixed to add propositions, and at this point, all flexibility is lost (Stracke, 2004).

Another option is the use of computer programs that support concept mapping. Computer-based mapping makes revising a concept map much easier Schanze and Grüß-Niehaus (2008). The nodes can always be moved around easily, dragging the edges with them. The process of improving the concept map shows the development of knowledge of the concept mapper (Novak and Cañas, 2008). Information is lost if only the final map is used to assess the knowledge of the mapper. Computer-based mapping makes it possible to watch the mapping history as a dynamic concept map (Rohles, 2021).

According to (Krabbe, 2014), students prefer using a computer instead of a pen and a pencil. He also mentions that computer-based mapping leads to more complex concept maps. A higher complexity is a sign of higher learning. A more complex map helps assess learning processes (Krabbe, 2014). Erdogan (2009) states that learners might experience stronger feelings of control and involvement in digital concept mapping.

A downside of computer-based mapping is the infrastructural requirements (Krabbe, 2014). The issue at hand pertains to digital devices in educational institutions. If no portable devices are available, walking the whole class to a computer room is necessary. Further, installing the programs in advance on the computers can be necessary. This can lead to a high expense for the teacher in advance (Stracke, 2004). To reduce the expense

for the teacher, Krabbe (2014) proposes to use an application that uses a web interface and a client-server structure. You can use all devices without needing to install anything beforehand. This also makes retrieving the concept maps much easier because they can be saved on a server (Krabbe, 2014).

Another downside of using computer-based concept mapping is that it adds further dimensions to these potential sources of bias: Some learners have higher competency in learning with digital tools than others. This can lead to concept maps of different qualities, although the mappers have the same understanding of the subject (Rohles, 2021). The same could apply to the mapper's learning experience. To reduce this risk, it is important that a tool is as user-friendly and as intuitive as possible for the students to use (Rohles, 2021). When the teacher wants to evaluate the retrieved concept maps, the biggest advantage of computer-based mapping comes into effect. According to Stracke (2004), using a computer for the evaluation makes the process much faster and gives the teacher many more options.

The success of a tool in an educational context depends on whether the users understand how to use the tool for learning purposes (Rohles, 2021). A tool for concept mapping could, for example, provide beneficial functionalities. Still, these might overwhelm the users if they impose too much cognitive load that would be ineffective for learning (Leppink et al., 2013). The tool should also provide a positive experience. The tool should be motivating for the user. Therefore, the tool shouldn't be too complex and provide many unnecessary functions.

The tool discussed in this work is a computer-based tool for the mapping process using a client-server structure as Krabbe (2014) proposed.

4.4 Evaluation format

An analyser must decide between the analysis on an individual and a group level (Krabbe, 2014). Creating an average concept map of a learning group called a "midi map" is possible. One difficulty during the creation of a midi map is the filtering of synonym concepts and linking phrases. A disadvantage of midi maps is that the information about the single mapper is lost in the process. It is possible to apply visual analysis techniques to midi maps, just like concept maps (Krabbe, 2014). On an individual level, the map of each mapper is analysed separately. Looking at each map is a process that is quite time-intensive.

On a base level, we can differentiate between qualitative and quantitative evaluation methods. The easiest way of using a quantitative approach to evaluation is to interpret concept maps as graphs and use the base values of the graphs like the number of edges, the number of nodes or the density of the graph (Stracke, 2004). There are several more complex options to score the quality of a concept map. One major distinction that can be made between scoring strategies is the distinction between strategies that compare a concept map with an expert map and strategies that score the quality (Krabbe, 2014). A downside all quantitative approaches have in common is that a good amount of information contained in concept maps is lost when the information contained in the concept map is reduced to one number. This is especially true for dynamic concept maps. The scoring of a map using digital concept maps is made easier by automation. Since we want to enable dynamic concept maps, we used a qualitative approach for the tool presented in this work. Therefore, we will not go into detail about different scoring options.

The qualitative evaluation of a concept map is more costly for the analyser. The analyser has to look at each map in detail to retrieve information. According to Ley (2015), analysers get faster with some training. Having an expert concept map for comparison can

assist the analyzer. Kinchin (2001) proposes simplifying the analysis process by dividing concept maps into three categories based on their gross morphology: spokes, chains and nets. Figure 14 shows the different categories. A spoke has only one level and shows a
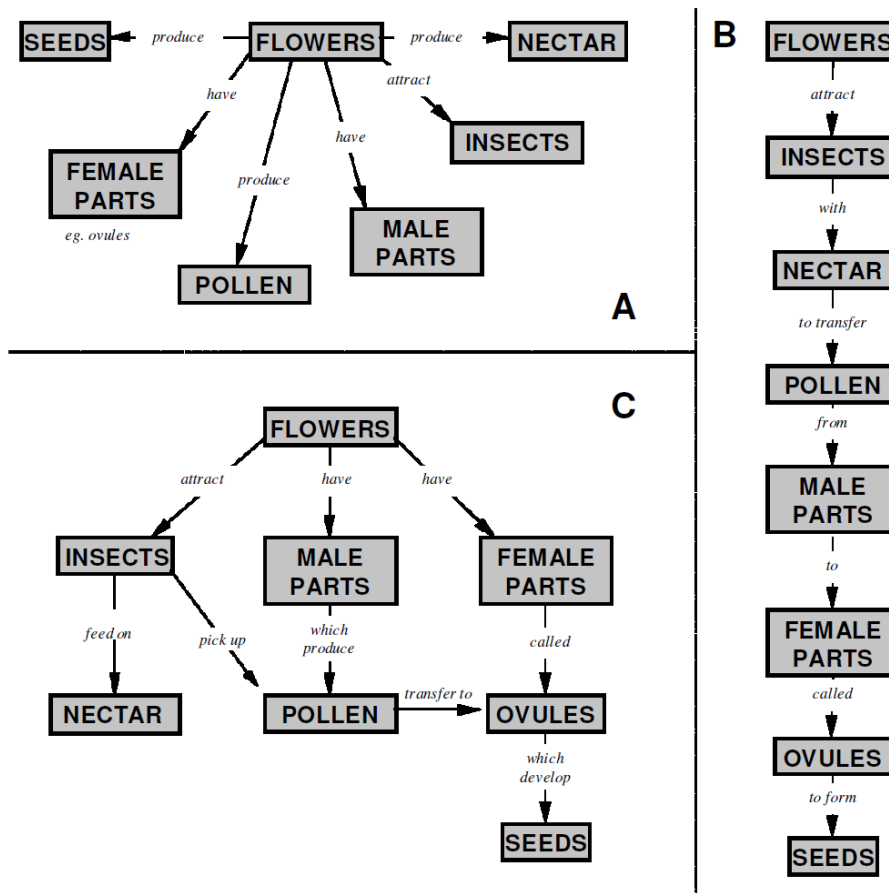

Figure 14 Quality description of concept maps as spokes(A), chains(B) and nets(C) (Kinchin, 2001).

simple association without understanding the process or interaction. A chain has many levels, but they are often unjustifiable. It can display a chronological order without intricate involvement or response. A net also has many levels, but they are justifiable because it shows the complex interaction of different conceptual levels (Kinchin, 2001). Kinchin (2001) proposes using the method to help the teacher find good constellations for collaborative groups. He says it is more a teaching than a tool for analysing (Kinchin, 2001).

Some projects aim to improve visual analysis for students by providing automated feedback. Ifenthaler (2009) used a method to highlight similarities between student and expert maps visually by colouring the proposition and concept the expert also drew. Another option to help visually analyse a concept map is to improve the layout. We show some algorithms that can be used to improve the layouts of concept maps to improve the analysis in section 3.

Few studies are concerned with layouts' effects on the analysis in an educational context. Lüthjohann and Parchmann (2011) used visual analysis to create a new science curriculum in German secondary schools' fifth and sixth grades. The students had to take the concepts and linking phrases from predefined lists. The tool MaNET were used for the analysis. A static anchoring layout method was used, which positions all concepts according to one reference map and simultaneously shows multiple concept maps next to each

other. Lüthjohann and Parchmann (2011) created for each curriculum an expert map as reference. To plan their instructions, they analysed the first concept map to get an overview of the knowledge of their students. They were able to adapt their instructions following the results. At the end of a unit, they analysed the final concept map of a student and compared it to the one from the beginning. This way, they could see a student's learning achievements. They could analyse the students' learning gaps by comparing the map to the expert map. This study shows the different information that can be drawn from the visual analysis of different maps. The layout used to support this comparison is simple. The positions of the nodes are static based on the expert map. A downside of this method is that the quality of the individual layout of the maps is probably bad.

Spener (2017) has researched in his work if the anchoring layout method does improve the comparison between different concept maps. He also researched if the linking layout technique supports the analysis of the learning advancement more than others. The third question the work tries to answer is if the potential upsides and downsides of the anchoring or linking method are combined in the mixed method. Spener (2017) used the tool Visone for his study. You can find further information regarding the tool in section 3.

Spener (2017) presented dynamic concept maps with different layouts about the topic of database systems to the participants. The participants had to answer questions of four different categories regarding the presented map:

- Local Comparison: What percentage of learners had drawn a particular edge at a particular time?
- Global Comparison: What percentage of learners connect peripheral concepts to a central idea at a specific time?
- Local Learning Progression: Did a learner draw a connection between two concepts from one point in time to another?
- Global Learning Progression: Has the learner made connections between the central concept and associated concepts at specific moments?

Spener (2017) tested how fast the participants could answer the different types of questions with different layouts. He used twelve different concept maps. For the anchoring method, an expert map was used. In addition to the quantitative analysis, he conducted a qualitative analysis using participant interviews.

The results show that a mental map supports the analysis speed for creating nodes and concept groups. The comparison of dynamic layout algorithms shows that the linking layout method has a significant advantage over the anchoring method for analysing learning advancement. The advantage of the anchoring method over the linking method for comparing different concept maps isn't significant but hints at the advantage of the anchoring method. This is supported by the results from the interviews that were conducted. Spener (2017) hypothesises that the advantage of the anchoring method could be significant if it were tested with less complex concept maps and a higher factor for stability. The average response time for the mixed method is between the linking and the anchoring version. This can be taken as a hint that the mixed method works, and the advantage of the linking and anchoring version can be utilized. Aside from this study, we found no research regarding the visual analysis of dynamic concept maps.

The analysis uses a qualitative approach applying the same algorithmic basis as Spener (2017).

4.5 The role of the teachers

Weinert (2000) stated that diagnostic competence is one of the four main competencies of a teacher. Diagnostic competence is the ability to assess a student's knowledge, learning progress, and performance during individual tasks (Weinert, 2000). Schrader (2013) separates the diagnostic of students into two processes: The final diagnostic for the judgement learning processes and the diagnostic during the lessons. The first is the foundation for granting authorizations, such as a qualification for university admission. The second one can be especially important for adaptions of the lessons to the state of knowledge of the students (Schrader, 2013).

This chapter has shown us that concept maps can be useful for both tasks. According to Stracke (2004), concept maps are a superior answer format than classic formats like short essays for learning goals in the field of structured connected knowledge.

Despite their potential benefits in the classroom, concept maps are not widely used in classrooms, as stated in Ley (2015); Kinchin (2001). Ley (2015) mentions in his work that a reason for this could be the high amount of work a teacher has to invest in using concept maps. A teacher has to select the task, response, and evaluation formats according to the goals. To achieve this, it is imperative to comprehend the multitude of options thoroughly. The evaluation format has to be chosen so that it reveals the information that the teacher is searching for in a time-efficient manner (Ley, 2015).

Kinchin (2001) sees the problem at the side of the scholar system. Reducing students' knowledge to a numerical grade is common, but this shouldn't be applied to concept maps. He mentions the scholar system in the UK, which can also be applied to the German system. This makes the usage of scoring attractive, but a lot of the value of the concept maps is lost. This comes with all the downsides mentioned in the previous chapter that essential knowledge in a map is lost. The analyser sees how good or bad a map is but doesn't see the weak points in the student's knowledge. This makes applying concept maps much less productive Kinchin (2001). On the other hand, the visual analysis approach is time-consuming, and the teachers must be willing to adapt to the findings. This can be even more time-consuming. Kinchin (2001) states that teachers are often critical of concept mapping because it could highlight inadequacies in their teaching or failure in their scheme of work. The stressful everyday work makes the work routine; consequently, teachers don't use their full capacities (Kinchin, 2001). This can also be influenced by a teacher's lack of time to look so detailed at every class.

It is unrealistic to convince all teachers to use concept maps, but it becomes more likely to convince a teacher if preparing, executing, and evaluating mappings is fast and easy, so a teacher has resources left to use the benefits of the maps. Since only doing the mapping for the sake of mapping doesn't bring any benefits (Kinchin, 2001). Concept maps are most effective when they are discussed, and the contained information is used.

5 The Tool

In this chapter, we will give an overview of the user groups, the design goals and the technical application of the tool we developed.

5.1 Objective

As described in section 4, concept maps and their applications in an educational context is a much-discussed subject in research. As briefly mentioned in the Introduction, creating dynamic concept maps can be difficult with most concept mapping tools currently available. Many of these tools lack options for creating dynamic layouts, making the analysis process more challenging. Additionally, it is not possible to export files for analysis in other tools due to specific file formats. A common standard for graph-like structures is the GraphML file format (Brandes et al., 2010). The Cmap tool utilizes the CMAP file format as an example. Files created in Cmaps cannot be imported into tools like Visone or the analysis part to be analysed as dynamic concept maps.

Tools supporting dynamic concept mapping, on the other hand, are often designed to create and visualise graphs and networks. While these tools can be useful for creating and analyzing dynamic concept maps, they may require background knowledge and offer unnecessary functions for students. This can make it challenging to apply these tools in educational contexts, where simplicity and ease of use are crucial for student success (Rohles, 2021). Furthermore, manual file collection is required when using these tools. If the task includes a skeleton map or a list of concepts, the task must be distributed to the mappers. This process is time-consuming and makes applying concept maps less attractive for teachers.

We extended the existing tool to enable the planning, creation, and collection of concept maps in an educational context more easily and efficiently. The tool focuses on making dynamic concept maps usable as a teaching, learning and diagnostics tool in an educational context. The tool's key objective is optimising an application in an educational context. According to section 4, a tool must be user-friendly and efficient to appeal to educators. At the same time, the tool should provide the option to create and analyse dynamic concept maps so that the most information possible is contained in the maps and can be extracted from them.

Therefore, the tool should provide high usability and be fast to use. Too many functions can make the usage of a tool more complicated and worsen the user experience (Rohles, 2021).

In English, usability is typically defined as the capability of using (Bevan et al., 2015). Several guidelines were published in the 1980s and 1990s to ensure that a product is usable, based on this definition (Bevan et al., 2015). Later, another more complex approach to usability emerged. This approach defines different levels of usability depending on the user and the goals this user wants to achieve. ISO 9241-11:1998 stated it is necessary to specify the goals and decompose effectiveness, efficiency and satisfaction (Bevan et al., 2015). This chapter will define the goals and outline the necessary criteria for the tool to achieve effectiveness and efficiency.

The tool should be constructed to be used from two sides. One user provides the list of concepts and potentially analyses the concept maps. Another user can use the concepts to create concept maps. So, in a classical educational setting, the teacher can provide the student with the task and later analyse the results. Therefore, we defined two user groups: the analysers and the mappers. The functionality can be divided into two sub-applications

in addition to the existing analysis part that work together to enable the collection and analysis of dynamic concept maps. The setup part of the tool allows a user to create projects containing concepts and users. The user should be able to schedule recordings for the project members. Later, the analyser should be able to download the collected dynamic concept maps.

The mapping part of the tool should enable the mapper to connect concepts represented by vertices to create concept maps and save them to a server.

The analysis part of the tool enables the creation of layouts for dynamic concept maps with the help of the mixed layout algorithm described in section 3.

5.1.1 User group

As it has been briefly introduced in the introduction section of this chapter. Two different user groups are defined: the mapper and the analyser. Utilize the mapping tool to generate concept maps from a roster of concepts. On the other hand, the analyser uses the setup and analysis parts of the tool. The analyser and the mapper can be the same if the user wants to self-assess.Figure 15 shows a schematic representation of the tool's structure. The analyser can create and manage projects that contain a set of concepts.
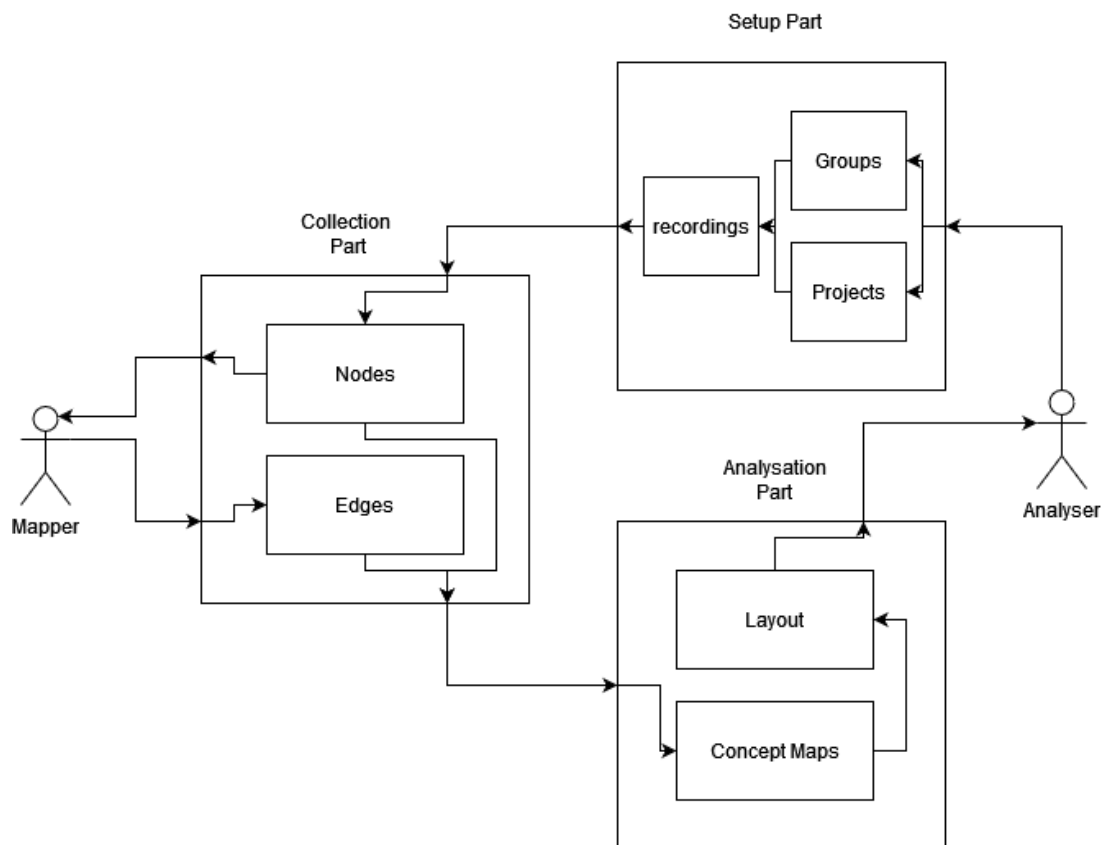
Figure 15 A schematic representation of the tool's application.

The analyser also can create and manage groups of mappers. The analyser can schedule recordings of a project for groups of mappers. Since the main field of application of the tool is an educational context, we imagined a teacher in the role of the analyser.

As mentioned in section 4, one of the main competencies of a teacher is the diagnostic competence (Weinert, 2000). This tool helps teachers assess students' knowledge at the unit's beginning, middle, and end. It also allows them to track progress and evaluate

teaching methods (Ley, 2015). Many other people would fit the role of the analyser, for example, students for self-evaluation. The usage of the tool is also imaginable at a university. The tool should be user-friendly for information science, teachers of other subjects, and all kinds of users. It should not necessitate extensive knowledge of graph layout algorithms.

The mapper can open recordings and create concept maps by adding directed edges between two concepts. During the creation, we imagined a student in secondary school as the mapper. So, the teacher could collect the dynamic concept maps during class and then analyse them later. However, it should also encourage the students to consider the connections between subject-related information. The mapping experience should encourage meaningful learning for students. The mapping can help the students to arrive at a deeper understanding of subjects (Novak and Cañas, 2008). Concept mapping can support the active process of structuring knowledge (Novak and Musonda, 1991).

5.1.2 Set-up part

The main objective of the set-up part is to enable the planning, creation and management of classes and projects.

Projects should contain a set of concepts. Classes should contain a set of people. The analyser should be able to create new projects. The analyser should be able to add and subtract concepts from a project. The analyser should also be able to create classes. The user should be able to add and remove users from these groups. Further, the analyser should be able to schedule the mappings of a project for a class. The analyser should be able to download the created maps by a particular class to a specific project. It is essential to have a login system in place to secure the setup process. The login should be secure. The set-up part should be easily accessible to schedule multiple recordings during a class. The setup process itself should be simple and fast to use.

5.1.3 Mapping part

The main objective of the mapping part is the creation of concept maps from a list of concepts. The mapping part should be easily usable for the mapper to enable multiple mappings during a lesson. It should be easy for the mappers to access the mapping. When opened, the mapper should be able to view the concepts represented by nodes. The nodes should be spread over the canvas. The nodes should be movable freely. The nodes need to be easily legible. The mapper should be able to modify the concept map by connecting or disconnecting two vertices as needed. It shouldn't be possible to add a label to the edges. The mapper should be advised to think of a label for the edge and draw the edge in the direction fitting for the label. The user must be granted the capability to save their concept map onto a server. The mapping process should be quick and straightforward without any sub-menus that could cause delays. The mapping part should be easily accessible during lessons.

The average Student is trained in the usage of digital media. Since time is a genuine concern during class, we wanted the tool to be as intuitive as possible for the mapper. Therefore, the handling of the tool should be based on control interfaces students know. This way, the tool can provide a positive experience, and the mapping process can motivate the user (Leppink et al., 2013).

The mapping part should contain a login. The login should be fast and don't cause any

delays. The login security is a lower concern since the mapper shouldn't be able to extract data.

5.2 Design

This chapter will give an overview of the design principles and why we implemented the tool the way we did. First, we will examine our fundamental decisions regarding the task and response format. Afterwards, we look at the setup and mapping part.

5.2.1 Response format

It was essential to use computer-based mapping because it makes revising a concept map much easier Schanze and Grüß-Niehaus (2008). To reduce the expense of the teachers, we decided to use a client-server structure as Krabbe (2014) proposed. This way, the teachers can easily access the maps created by the students on the server. As mentioned in section 4. One downside of computer-based mapping is the factor of available devices. The digitalization status of German schools is outlined in Jude et al. (2020). Since June 2019, schools can apply for funding from the "DigitalPakt Schule". With those funds, the digital infrastructure at schools and the creating of pedagogic concepts for schools should be supported. But at the end of 2019, only 0.01% of the funds were spent. One reason for the slow spending is that each purchase must be advertised throughout the EU. The state of digitalization at German schools is very different from school to school. The availability of enough devices can be challenging, but the "DigitalPakt Schule" is a positive step forward and offers hope for the future.

Mapping software installation on multiple devices is a challenge. Rohles (2021) has tested, in his work, on which device students at secondary schools in Luxembourg prefer to do the mapping tasks. 50 % of the students preferred tablets, 41% of the interviewed students preferred computers, 3% preferred paper and 1.5% preferred Smartphones. Since the preferences between tablets and computers are spread nearly evenly, the tool should be available on both platforms. Digitalization in schools is under the jurisdiction of the federal states, resulting in a rapid variation of available devices. We decided to design a web application to make the mapping environment accessible on all platforms and devices. A web application has the advantage for teachers that no prior installation is necessary. This can make the inclusion of mapping activities much easier.

We applied responsive design principles to ensure a seamless user experience across all platforms and devices.

Design (2013) wrote, "The goal of responsive web design is to make a web page look equally good regardless of the screen size of a device." Responsive web design allows web pages to adjust to device screen sizes with a flexible layout. Figure 16 shows how the web page looks on an Oppo a94 5g with a screen size of 1080x2400px and a PC screen with a resolution of 2550x1024px. If the screen size is below 768px, the control elements shrink, and the layout grid is shifted to the side. The layout automatically fits the screen size when a user opens the website. The website should provide all the features the PC version also provides. We had to find workarounds to emulate PC functions naturally on devices without a mouse and a keyboard. For instance, press the left mouse button. Since a touchscreen doesn't provide two different buttons, we have to differentiate the triggering of two different events differently. A possible solution is to distinguish between two inputs by their duration. One downside of responsive web design is that the content of a page
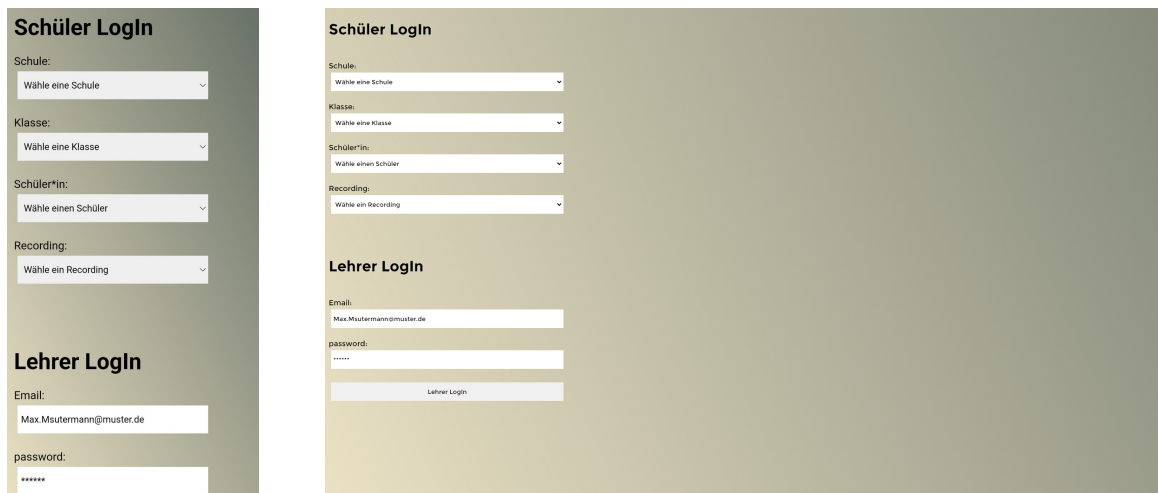
Figure 16 The main page on different screens: left on a smartphone and right on a PC.

is usually shifted to the bottom if there is not enough space on the sides. According to Kim (2013), web pages can become excessively long despite having minimal content. Kim (2013) advises on creating a good, responsive website. We adapted some of the advice as design goals:

-   Make essential content and popular services more discoverable by removing access content from both desktop and mobile websites, especially the home page.

-   Provide comprehensive content and full features on the mobile site to ensure users can access all essential information and features.

-   When designing a mobile website, it's important to maintain the same content and features as the desktop site while prioritizing and organizing content differently for mobile use cases. This will help ensure mobile users can easily navigate and access the content on a smaller screen.

-   Make complex tasks on mobile user-friendly by revealing information gradually.

-   Ensure that each of your mobile pages is easily navigable and user-friendly.

5.2.2 Task format

As described in section 4, concept maps vary immensely in dependency of the task format (Kinchin, 2014).
An objective of the tool is the usage of the created concept maps as a learning and analysis tool. Because of that, we decided on a create-a-map task. As mentioned in section 4, there is a trade-off between the freedom of the task and the information contained in the map. The more restricted a task is, the faster and easier the mapping, but the representation of the mapper's knowledge worsens. That doesn't necessarily mean the quality of the concept map gets worse. On the contrary, the concept maps with a list of concepts get more explanatory (Cañas et al., 2012). One reason is that the mapper isn't confronted with the problem of an empty paper. The mapper has a starting point and can start fast and easily create the map. Since one of the objectives is to enable multiple mappings within a lesson, we decided on a restricted task format. The mapper can only use a restrictive list of concepts the analyser provides. The task wants the mapper to think of labels for the connections but omit them in the concept map. A downside when omitting the labels is that information is lost. Novak and Cañas (2007) even calls linking phrases

a key indicator of active learning. The learning has been happening since the propositions were created. It is just harder to track the state of knowledge. Since the mapping speed is such an important factor for the usage in the classroom to make the tool more attractive for teachers, we think the improvement of the mapping tempo makes up for the loss of information. Even without the labels, the teacher can withdraw a lot of information from the maps since the connected edges give a clear picture of whether the mapper sees a connection between the two concepts. An upside when providing a list of concepts is that it can lead to more explanatory concept maps, as mentioned in section 4. This can make analysing the map easier (Cañas et al., 2012).

5.2.3 Set-up and mapping part

We separated the setup and mapping pages into two pages behind two different logins. The logins can be found on the main page. A main page like this enabled access to all parts of the tool using a single QR code. Figure 16 shows the main page. The login for the analyser uses a server-sided login with an email address and a password. Security was the biggest concern for the login. The tool uses the Firebase authentication to check if the login data is correct. For the student login, we decided to use a simplified version. The students can select their school, class, name, and the recording they want to do from drop-down menus. The students can't create their own accounts. The teachers have to create the classes and students with the setup part. We decided to use this method because security wasn't the greatest concern since the students could extract no data. Students only can do mappings. The main goal for the student login was to make the login fast and easy. No time is lost in creating the accounts when the tool is used the first time, and if the students don't have a password, they can't forget it. The teacher can use pseudonymization for school classes and names. The analyser could use a combination of the date of birth and a letter instead of names. Another option would be to use the student number in the class list.
The setup page should allow the mapper to create and manage classes and projects. The setup page is structured symmetrically. The analyser can use two drop-down menus to select already existing projects and already existing classes that are linked to this teacher. The teacher can add new classes and projects using two buttons that open pop-up dialogues. These dialogues can be used to enter names for new projects and classes, respectively. The students in a class can be managed with a dynamic list. The same is true for the concepts in a project. The analyser can download the files of a class from a project using a button and set a recording for all class members using another button. We aimed to simplify class and concept management for the analyzer with these intuitive controls.
When a mapper opens a recording, the mapper sees all the concepts encapsulated in circles. The concepts are spread randomly across the screen, which is true for every project recording. The mapper can easily bring new structures and ideas into the map. The mapper does not have to experience fear when faced with a new paper, as described by Cañas et al. (2012). The page offers only the essential controls. The controls are all on the surface level, so no sub-menus need to be opened by the mapper.
We tried to keep the visual design of the web application clean and visually appealing.

5.3 Technical application

In this chapter, we will give an overview of the technical application of the tool. We will show which existing libraries, formats and services were used.

5.3.1 Set-up and mapping part

The tool's setup and mapping must be scalable across different devices and platforms. Because every device provides a browser, we designed a web application for this part of the tool. Therefore, we created a web application using HTML, CSS and JavaScript.
The web application is composed of two pages. The main page and the teacher page. The main page provides a login for the students and a login for teachers. When a student is logged in, the page shows the concept nodes. To fit the text inside the nodes, we used textfit.js. Textfit.js is a jQuery-free component that quickly fits single and multi-line text to the width and height of its container. In our case, the containers are the nodes. (Reed, 2021) Text fit.js is under an MIT license. So, the software is free to use in any context. The controls for the screen can be found in the script.js file. We decided against the use of pictures for the nodes and edges. They were created from basic CSS components. This way, they are easily scalable, and the style can be controlled from the CSS file.
The mapper can move the nodes and add directed edges between them. When the teacher is logged in, the page opens the teacher page. The teacher page allows the analyser to add and manage classes and projects. The analyser can also schedule recordings. It also enables the download of a zip folder containing the concept maps of a class for a project for each recording as a GraphML file. The folder and the files are created locally in the browser from the data in the database. We used a combination of two extensions to create the file and folder. First, we used Filesaver.js for the creation of the GraphML files. FileSaver.js is the solution to saving files on the client side and is perfect for web apps that generate files on the client.(Wärting, 2022) FileSaver.js under an MIT licence. It is, therefore, free to use in any context. For the creation of the zip folders, we used zip.js. zip.js is a JavaScript open-source library for compressing and decompressing zip files (Lormeau, 2023). The expansion is under a BSD-3-Clause license. Therefore, the use in any context is permitted.
Since the setup and mapping part comprises two web pages, the first page shows the login for the analyser, the mappers and the mapping part. The logic for the login controls can be found in the script.js file. When a user logs into the mapper, the controls disappear from the page, the project data is retrieved from the database, and the nodes are then added to the page. The node and edges logic can be found in the node.js and arrow.js files. The style for the controls, the nodes and the edges can be found in the style.css.
When a teacher logs in, the teacher page is loaded. The page shows the controls for the teacher. The logic for the teacher page can be found in the teacherscript.js. The style for the teacher page is also contained in style.css.

5.3.2 Backend

We utilized *Firebase* for the backend. Firebase is a backend service platform by Google. Developing web applications without needing server-side code when using Firebase is possible. Firebase handles the hosting, authentication and database needs of our tool.
For the hosting, Firebase uses a content delivery network. That means a network of servers worldwide provides an up-to-date copy of the web page. This feature makes the web page

available worldwide without long loading times. Firebase enables the deployment of a web page and rollback with a single command. Another advantage of Firebase hosting is that the web page is secured automatically with an SSL certificate.

Firebase also provides an authentication service. This service allows checking for identities on the server side during the login. The authentication service enables users to authenticate in several different ways. They can use an account with another application, such as Facebook, Twitter, or Google. At this point in time, the tool only supports a login using a combination of email and password. But this can be expanded easily (Brown and Safari, 2020).

Further, we used the Firebase *Firestore* database. This service enables the storage of data on a server in a database. This is possible without much backend code. Firestore is a Document-Oriented database. Data is stored in documents, which are organized in collections. A single document can store simple data types, lists and different objects (Brown and Safari, 2020). When creating the structure for the database, the goal was to build it as efficiently as possible but still have enough options to expand it later. We created four collections. One collection holds a document for each registered teacher. Each document stores an ID, a school and the last login date. One collection stores the projects. Each document contains an ID, the name, the number of nodes, a list of nodes and the teacher that owns the project. One collection contains the mappers. Each document in this collection contains an ID, a name and a class. It also stores a sub-collection with the recordings. Recordings stores documents for each conducted and scheduled recording for this user. Each document in the collection contains an ID, a value that shows if the recording is done, a timestamp that shows when the recording was scheduled, an adjacent list, a list that contains the positions of each node and the ID of the Project. Another collection stores the classes. Each document contains an ID, a name and a school. This class isn't really mandatory for the data structure at this moment in time. Additional information about the classes probably needs to be stored in future extensions. Figure 17 shows a schematic representation of the composition of the database.
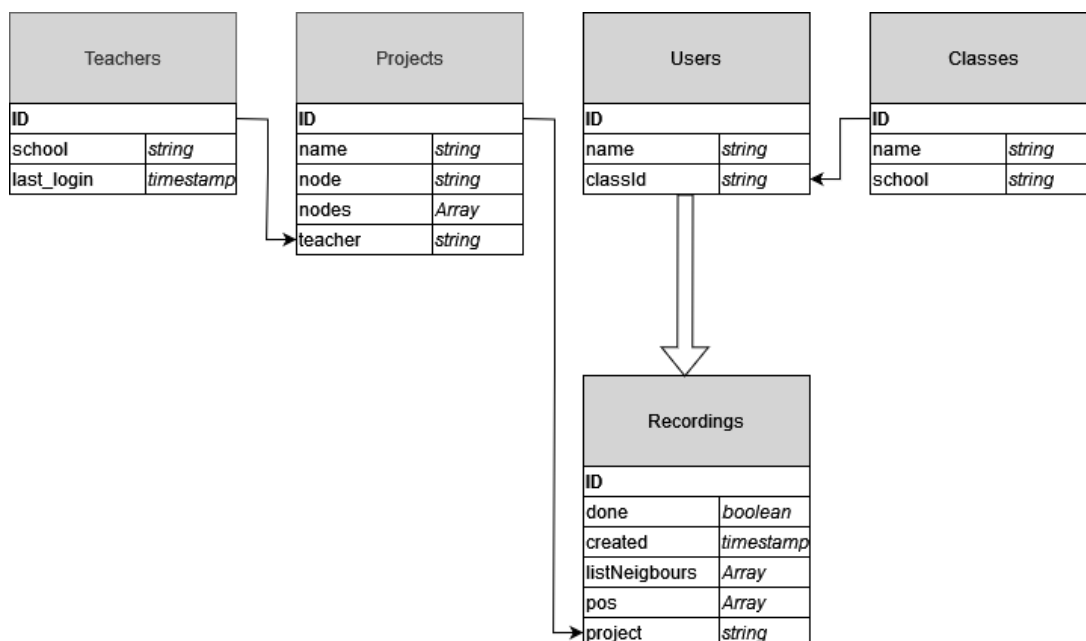

Figure 17 A schematic representation of the database.

5.3.3 File format

The tool uses the GraphM file format as a medium to transfer the maps from the web application to the analysis part. The GraphML (GraphMarkupLanguage) was created to store and exchange graph-related data. The GraphML file format uses the *XML* syntax, which means it can be combined with other XML-based formats (Brandes et al., 2010). The file format was designed as a standard for graph visualisation tools. Following this goal, most existing graph visualisation and drawing tools support GraphML files (Brandes et al., 2010). An example would be Visone.

The GraphML file format is designed to store all kinds of graphs. This also applies to concept maps. It enables the storage of concepts as nodes with a specific shape, size, colour and label. It also allows the storage of propositions as lines with different visual options and a label. The position concepts are stored with an absolute coordinate value, and the propositions have a start and target concept. The file format was designed to be easy to parse for humans and machines (Brandes et al., 2010). This makes the creation and usage of the files easy.

To store dynamic concept maps, we use multiple files, each representing an instance of the dynamic concept map. A folder contains all files for one dynamic concept map. Each file contains the same set of nodes and an individual set of edges. When using the download function, all files containing the instances of a dynamic concept map are stored in a zipped folder. We use zipped folders to reduce the size of the files.

This is the standard Visone also uses. This way, we can ensure maximal compatibility.

5.4 Application example

To understand how the tool operates, an exemplary use case can be helpful. We will show how an analyser and a mapper use the tool from two different sides. Because of that, we will assume an analyser who wants to check on a group of people's knowledge at various times. We assume that there is a mapper who is a member of the group of people. Specifically, we assume that the analyser is a teacher and the mapper is one of the teacher's students.

5.4.1 Analyser

The user needs to go to the website's main page to begin the analysis. The analyser uses the teacher login to go to the teacher page. To access the teacher account, two text input fields and a button are used for authentication. The tool utilizes Firebase authentication to verify the accuracy of login information. Figure 16 shows the main page. The teacher login is below the student login. The browser opens the teacher page. On the teacher page, users can create and manage projects and groups. Figure 18 shows the page when it is opened. Two drop-down menus can be opened to select an existing project and a class linked to this teacher. When one of the two buttons is pressed, a pop-up dialogue opens. The teacher is being requested to provide the name of the new project. The same principle applies to the classes. If the black button with the plus beside the class drop-down menu is pressed, a pop-up dialogue appears and asks the teacher to enter a name for the class. If the analyser creates a new class or project, it is selected automatically.

In our case, the mapper selects a class and a project. If the project is selected, the page shows the menu to control the concepts contained. In Figure 19, you can see the menu below the class selector. The menu consists of a text input field on the top with a black
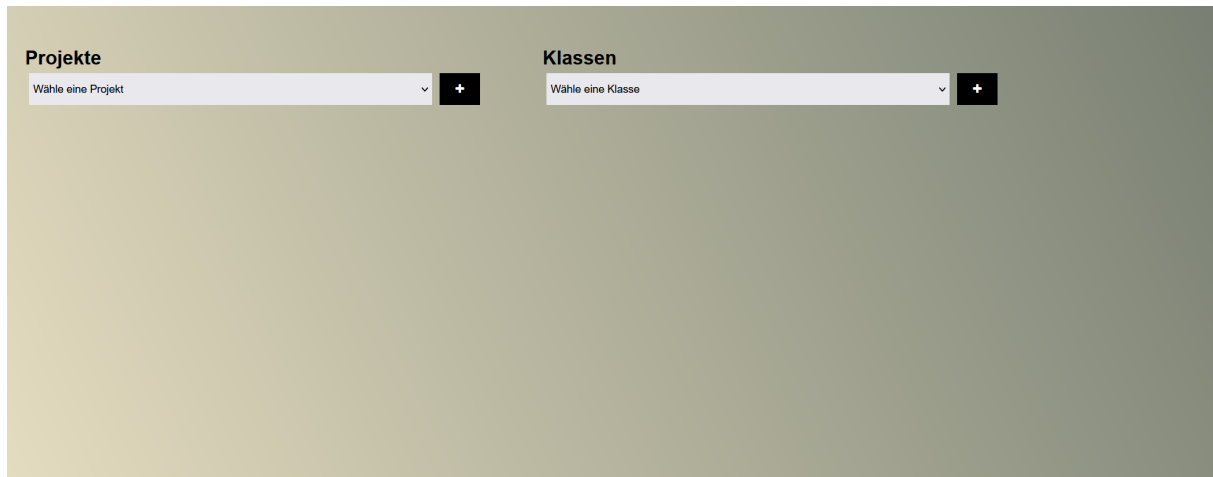
Figure 18 The teacher page when after opening it.

button with a plus on its side to add a concept to the list of concepts below. Each element in the list has a red button with an "x" to remove the concept from the list. When a class is selected, an equivalent menu opens below it. This menu enables the management of the members of the class. Our analyser adds some concepts to the projects and some members to the selected class. When a class and a project are selected, two further
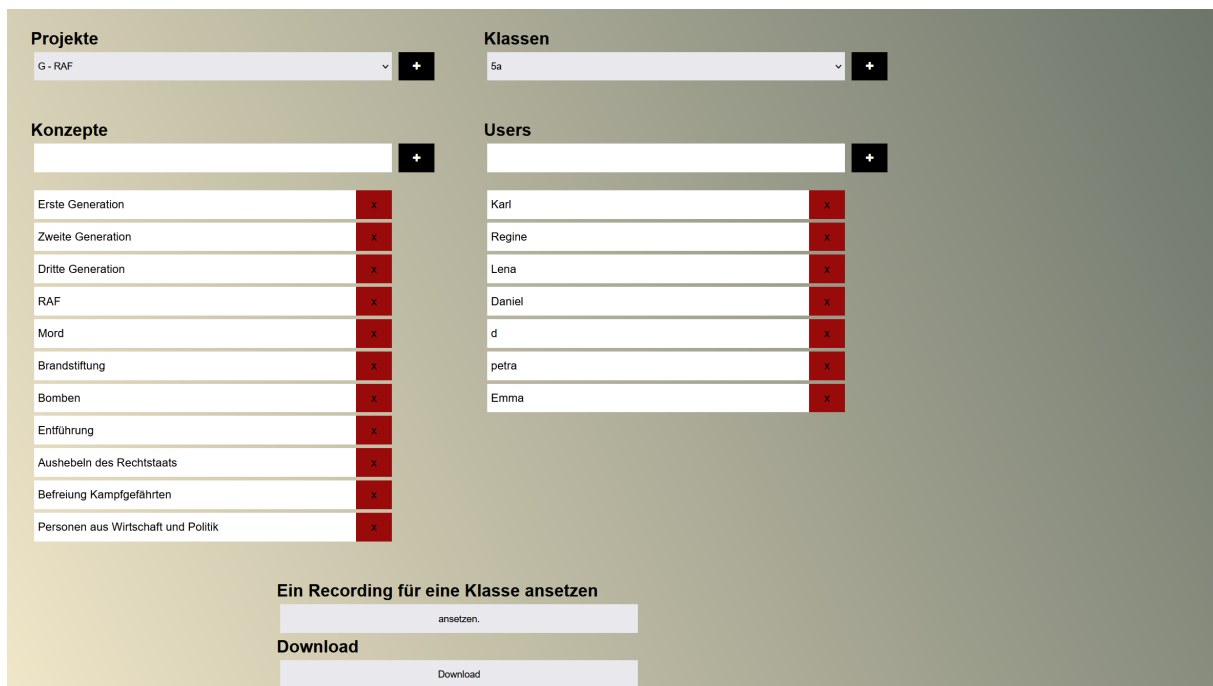
Figure 19 The teacher page with a project and a class selected.

buttons appear. One of the buttons creates a recording for all selected class members for the selected projects. The other enables the download of all concept maps the selected class created for the project. So, our analyser schedules a recording of the selected project for the selected class. The analyser does that several times over a few days, giving the mapper time to create the maps. Afterwards, he downloads the concept maps as a zip folder.

The analyser unzips the folder and opens the analysis tool or another tool to analyse the concept maps like Visone. If the analysis part is used to analyse the created maps, the

analyser can open the unzipped folder and select the folder of one of the mappers. The tool shows the dynamic concept map created by the selected mapper. The analyser can switch between the instances of the concept map but has problems comprehending the information in the concept map. To make analysis easier, adjust the factor between the stability of the visualisation. Then, the analyser inputs an anchor and sets the factor between anchoring and linking. Afterwards, the other controls are set, and the layout generation is started.

Following that, the analyser switches between the instances of the concept map again but isn't satisfied yet. The analyser repeats the setup and layout generation several times until the analyser finds the perfect layout. The usage of the analysis part is presented in detail in Martin (2021). Figure 20 shows a map visualized with the analysis part. In the appendix are examples of a dynamic concept map using different settings.
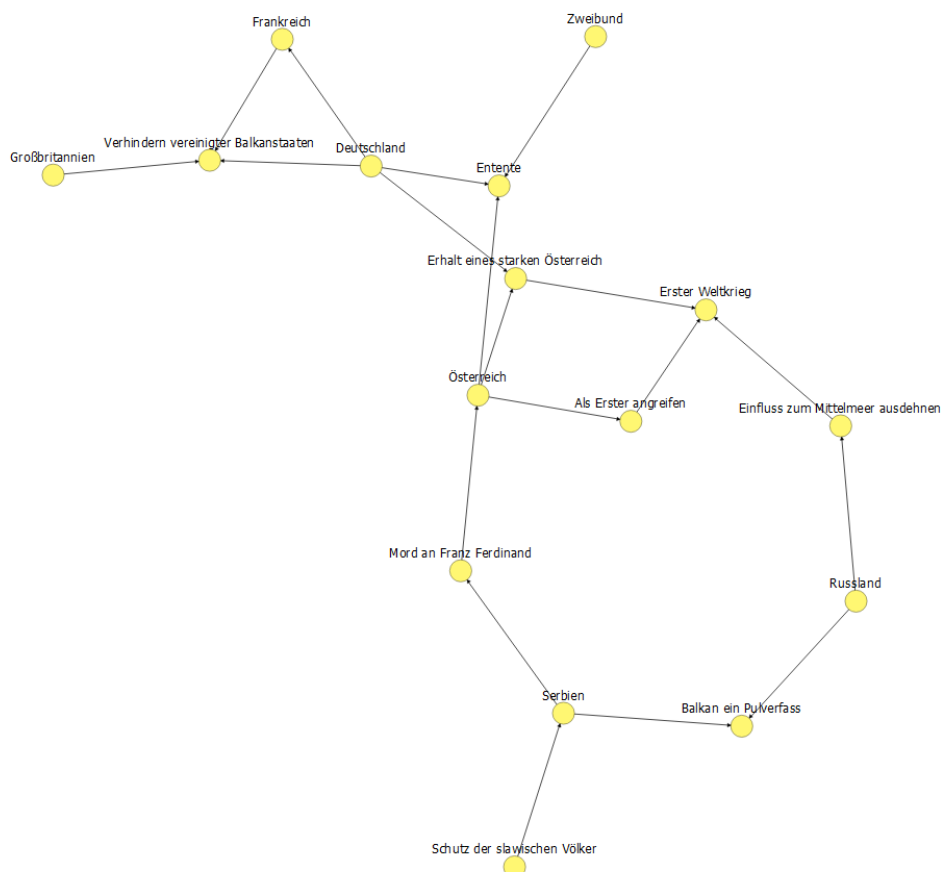
Figure 20 A concept map visualized using the analysis part.

5.4.2 Mapper

The mapper opens the main page of the web application. Figure 16 shows the main page. He uses the student login to sign in. The student login contains four drop-down menus. The mapper can select the school or organization with the first drop-down menu. With the second drop-down menu, the mapper can select the class or group he or she is part of. The menu shows only the classes or groups of the selected school or organization. With

the third menu, the mapper can select the person. The menu only shows the people in the selected class or group. The name of the person can be a code or a pseudonym. With the fourth menu, the mapper can select the recording. It only shows the recordings that haven't been conducted yet. When the mapper has selected a value for all the menus, the submit button appears. The mapper presses the submit button. After submitting, the button will visually shrink and then return to its original size to provide feedback. The controls are hidden, and the concepts of the selected project are shown. Figure 21 shows the mapping page. When the mapper opens the mapping page, the nodes are spread
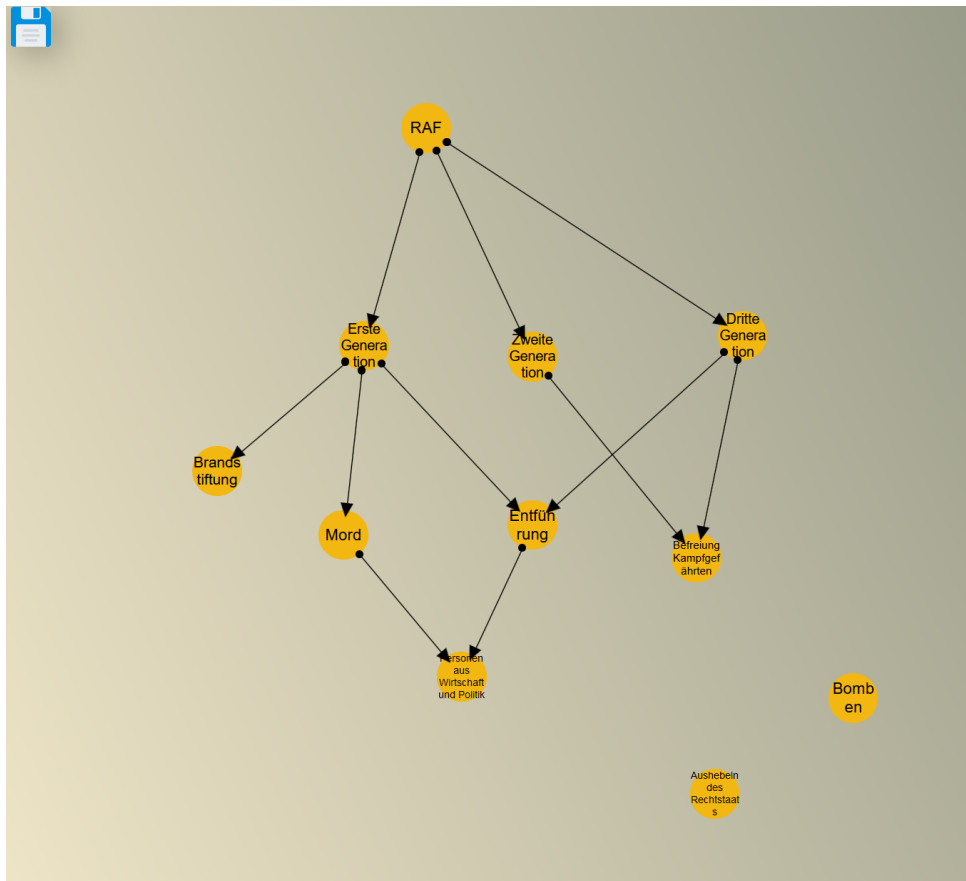

Figure 21 The mapping page after the mapping process.

randomly over the screen size. The mapper can move them freely around by pressing the right mouse button on them or a touchscreen by touching them. The mapper can add edges by pressing the left mouse button on a node. When the node is pressed, an edge appears. The endpoint of the edge is connected with the node that was pressed, and the mapper can drag the tip. To connect the second node, the mapper has to drag the tip of the appearing arrow onto another node. The mapper can press a node for half a second on a touchscreen without moving it. Next, an edge will appear, and the mapper can drag it onto another node. By using this method, the mapper can establish a connection between two nodes through a directed edge. If mappers want an edge in both directions, they can add edges in both directions. Edges that loop from a node towards themselves are disabled. The mapper can also move the edges by moving the tip or the endpoint of an edge. This way, the mapper can change the connection from one edge to another. If the mapper wants to delete an edge, she/he can move the endpoint or the tip towards the space between the nodes. When the mapper stops dragging there, the edge will disappear. After our mapper arranges the nodes and adds all edges, the mapper can press the save

button on the top left of the screen. As you can see in Figure 21 the save button is represented by the picture of a floppy disk. The button gives visual feedback that it was pressed by shrinking slightly and returning to its original size. When the save button is pressed, it opens a dialogue asking if the mapper wants to save. After the mapper confirms the dialogue, the page displays, "Thank you for your participation". The mapper can reload the page and record again if another recording is scheduled. Figure 22 shows a user interaction diagram of the mapping part.
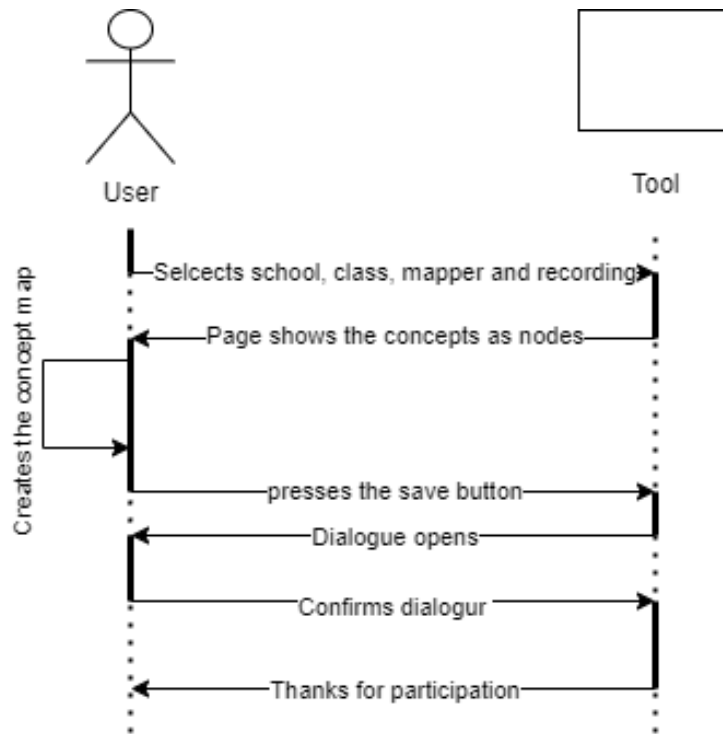

Figure 22 User interaction diagram for the mapping part.

6 Experimental evaluation

Empirical research can be divided into four phases. Within this step, the research question gets formed and specified. In the second step, the data collection is planned and prepared. After this, the data is collected. In the fourth step, the data is evaluated and finally documented (Häder, 2010).

6.1 Research interest and research question

Concept maps could be a great tool to facilitate more meaningful learning at schools Novak and Cañas (2008). We designed this tool to make dynamic concept maps more attractive in an educational context. For the evaluation of the tool, we will focus on the tool as a whole, including the analysis part. The tool presented in this work aims to enable dynamic concept map planning, creation, collection and analysis. Several tools support computer-based mapping but focus on the evaluation using scoring techniques and don't provide options to improve the visual analysis of dynamic concept maps. At the same time, those tools aren't efficient to apply in an educational context. We designed the tool presented in this work to be optimized for usage in an educational context. Therefore, the tool should provide high usability and be fast to use to be attractive for a teacher to use in lessons. At the same time, the tool should offer the option to create and analyse dynamic concept maps so that the most information possible is contained in the map and can be extracted from the map. The tool enables the fast retrieval of all created concept maps using a client-server structure. The tool allows for the layout of the collected dynamic concept maps using the mixed layout method to analyze the created maps easier and faster. Spener (2017) has shown that the mixed layout method can accelerate the analysis speed when looking at different instances of one dynamic concept map and comparing multiple dynamic concept maps. He proposed to test the results of his work in practical experiments to face the expenditure of time for the teacher with the advantages for the students.

We previously tested the analysis part's usability. Now, it needs to be proven in an educational setting as well. To see if the tool and the mixed layout algorithm work in an educational concept, we tested the tool at a general high school in Baden-Württemberg. To do that, we evaluate how applicable the tool is in an educational context and what advantage it can bring. A central part of this question is if the evaluation format using the mixed layout method brings the benefits Spener (2017) mentioned and enables a fast and reasonable evaluation of dynamic concept maps. We want to answer the Question:

Can the tool bring benefits in an educational context?

To answer this question, we try to answer the sub-questions.
- In how far is the design and implementation of the tool suitable for the application in an educational context?
- In what way does the tool support using concept maps as a learning, teaching and evaluation tool?

In the following chapter, we describe the research design.

6.2 Research design

This chapter presents the choice of methods and the procedure of the research.

6.2.1 Methodology

According to Weßel (2010), an essential part of the software development cycle is the discussion and evaluation of design and implementation results. Qualitative research methods from the social sciences ideally complement the methods used in software engineering and statistical analysis Weßel (2010).

Since the time window for creating the master thesis is only four months, and the tool had to be implemented and tested within this window, it wasn't possible to test it with many different classes and teachers. Quantitative research wasn't possible since the number of participating teachers is limited. Therefore, we used a qualitative research approach.

The quantitative approach includes more significant numbers of cases, is standardised, and focuses on measuring and operationalising. An in-depth look at fewer cases will be taken in the qualitative approach. The focus lies on the understanding of the backgrounds (Häder, 2010). The tool's functionality is a complex question with multiple user groups, so it is necessary to have an in-depth look. The qualitative research approach offers a significant advantage in terms of flexibility. Reacting to fresh insights promptly is permissible and highly encouraged (Weßel, 2010). When it comes to IT projects, qualitative research is typically a process that involves multiple iterations (Weßel, 2010). Because of the limited time, doing multiple testing cycles was impossible.

Qualitative research methods include covert and overt observations, individual and group interviews, and document analysis. Applied to IT projects, this involves observations, conversations, and document analysis. Data is collected through protocols for observations, notes and transcripts of interviews (Weßel, 2010). Of the qualitative research methods, observations and individual and group interviews are particularly suitable for IT projects (Weßel, 2010). As we have mentioned in section 4, teachers play an essential role in applying concept maps in an educational context. Therefore, we conducted a semi-structured interview with a teacher after testing the tool with multiple classes. According to Weßel (2010), the interviewee should have several years of experience as an employee of the organization, with a good understanding of the organization, its workflows, and its collaborations with external entities. This leads to the synonym "expert interviews" for semi-structured interviews. Therefore, we selected an experienced teacher with 25 years of teaching experience to interview. There are two primary purposes during interviews: Firstly, the interviewer uses the provided guidelines to guide the conversation and topics. Secondly, the interviewee can speak freely. This offers the opportunity to describe problems and come up with solutions. It's also important because it allows for aspects the interviewer may not have previously considered, which can lead to new insights being discovered Weßel (2010).

The teacher agreed to record the interview. The interview was 25 minutes long. We transcribed it using a clean read or smooth verbatim transcription method (Mayring et al., 2004). So we transcribe speech exactly but remove the filler and embellishing words. We also convert dialects and abbreviations to standard German. The transcribed interview can be found in the attachments.

We used summarizing content analysis to evaluate the interview based on the method by Mayring et al. (2004). The analysis aims to isolate specific aspects of the material, create a cross-section based on predetermined criteria, or evaluate the material based on specific criteria.

Since the tool is designed to be used by teachers and students, we also wanted to evaluate the students' impressions. The federal state of Baden-Württemberg prohibits structured research with students without an approved application from the Ministry of Education. The time window of the master thesis was too small to apply for approval. Because of

that, a quantitative or structured evaluation with students wasn't possible. Therefore, after each block, we conducted an unstructured open discussion about the tool. The teacher moderated the open discussion about the tool after the testing. We made notes about all the comments of the students. In addition, we observed the students carefully during the mapping and noted the results.

6.2.2 Participants and Procedure

The study was conducted in a secondary school in Baden-Württemberg with an eighth and ninth grade in history. The eighth grade consisted of 25 students, and the ninth grade of 26 students.
We have only encountered research focusing on utilizing concept mapping tools in science. However, it is quite likely that a science teacher has more knowledge about digital mapping tools than a humanities teacher. Because of that, history was chosen as the subject for the study.
The teacher has 25 years of teaching experience. The teacher mentioned that they often use mind mapping and time beams to structure student's knowledge.
The contact with the teacher for the interview was established during my internship semester. After contacting the teacher for the research, the teacher got an introduction to concept maps and the tool. This introduction contained a short presentation of all the essential functions of the tool and the benefits it could bring. According to Weßel (2010), it is important to clearly communicate the confidentiality and benefits of the interview to the interviewee.
Afterwards, the lessons for the testing were chosen. A block of four lessons with an eighth grade about the beginning of the First World War was chosen. Further, a block consisting of two lessons about the "R.A.F" and a block of two lessons about the society in the 1960s in Germany with a ninth grade were chosen. I conducted the first block, and the interviewed teacher conducted the second and third blocks. During the first block, the interviewed teacher was spectating.
The objective was to incorporate mapping into various lessons. The goal was to improve the lessons without feeling foreign to emulate the application in a regular lesson. The lessons follow the typical structure of history lessons, starting with an introduction containing the lesson's theme. Most of the time, the opening leads to a central question that is answered throughout the lesson. The introduction is followed by work and backup phases. During this phase, new knowledge is acquired that can help answer the lesson's central question (Rohlfes, 2005). During the work phases, the students work with primary or secondary sources alone, with a partner or in groups. At the end of the lessons, the learned content is used to answer the central question. We placed the recordings after the work and backup phases. That way, it is possible to see the evolution of knowledge since the students can acquire new knowledge between each recording. This should help the teacher to see if the work phase helped the students to gain a deeper understanding. This structure should also help the students structure and contextualise the newly acquired knowledge with the old knowledge. The lesson plans are in the attachment.
The data collection was executed in June 2023. The research was conducted in the usual classroom of the students to facilitate student participation and to purposefully observe the actual context in which the tool will be used. This also meant the environment wasn't as controlled as in a laboratory. Before the first mapping, the students were introduced to concept mapping by explaining its characteristics. Since mind maps were known already, we explained concept maps based on the differences from mind maps. We also presented

an example concept map. The students used their private phones or iPads provided by the school. One problem with using private phones was that the students had no Wi-Fi access using private devices.

As mentioned in the section 5, all concepts for the whole block were available to the students from the start, and the students always started with random placement of the concepts. While they tested the tool, the participants were observed carefully, and problems were noted.

After each block, the teacher moderated an open discussion. The comments of the students were noted. After the lessons, the teacher analysed the recording results using the analysis part of the tool. Then, the teacher was interviewed. The interview was recorded and later transcribed.

6.2.3 Interview guideline

The interview starts with a greeting followed by the questions. We designed the questions for the semi-structured interview as open questions. We tried to avoid suggestive questions. The questions were not ordered to answer the research questions but in two thematic blocks to make the interview more fluid. The first four questions are concerned with the perspective of the students. The fifth to tenth questions discuss the teacher's perspective on the tool. Questions 5 and 8 have optional follow-up questions for more specific information about an aspect.

1 What advantages do using the program and digitally creating concept maps offer students?

2 How would you evaluate the concept mapping method with predefined nodes compared to other methods like a timeline or mind maps?

3 To what extent do you believe the concept mapping method helps students achieve a deeper understanding of the lesson content?

4 In your opinion, how much support did the students need to use the program?

5 How does the tool assist you in assessing the students' performance?

    5.1 Which layout method provides the greatest value?

6 How much support would you need to use the program?

7 In what ways would it ease your workload?

8 How can the tool be integrated into the curriculum?

    8.1 During which phase of the lesson can the tool be applied?

9 How often would you use the program in your teaching?

10 What additional features would you wish for in the program?

The interview was conducted in the German language. The original German questions are provided in the appendix. The guideline provides question formulations but allows for adaptability during the interview. The order of the interview questions can be adjusted to match the interview flow.

The questions for the open discussion with the student were also based on this questionnaire, but the discussion was conducted openly.

6.2.4 Analysis

The content analysis's basis is the interview transcript described in the earlier chapters. The methodology employed in this study is founded on structuring qualitative content analysis by Mayring et al. (2004). We adapted the method to fit the research question and the research circumstances. This was necessary since only a single teacher was interviewed. Figure 23 shows the schedule for the deductive content analysis. Mayring et al. (2004)
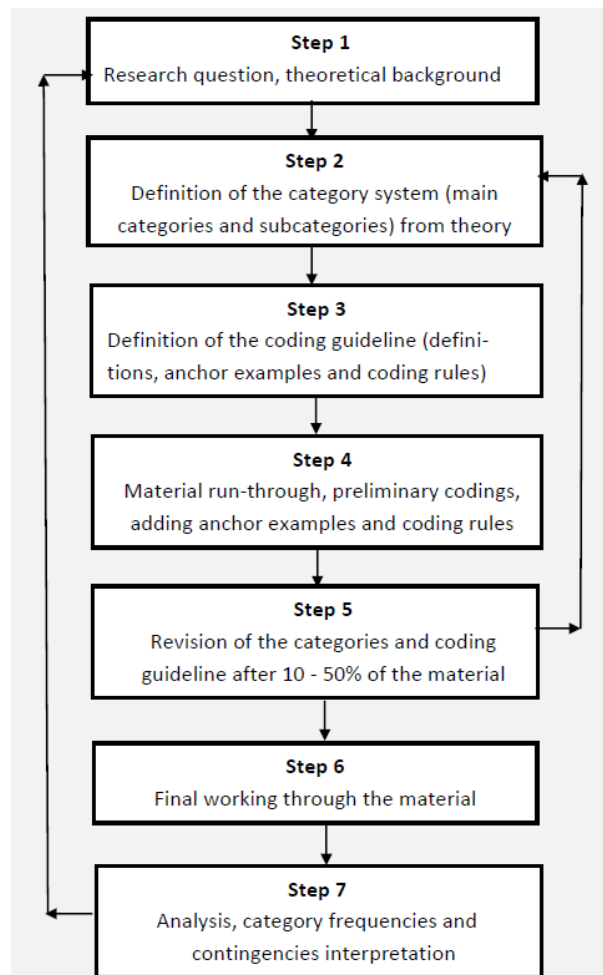
Step 1
Research question, theoretical background

Step 2
Definition of the category system (main categories and subcategories) from theory

Step 3
Definition of the coding guideline (definitions, anchor examples and coding rules)

Step 4
Material run-through, preliminary codings, adding anchor examples and coding rules

Step 5
Revision of the categories and coding guideline after 10 - 50% of the material

Step 6
Final working through the material

Step 7
Analysis, category frequencies and contingencies interpretation

Figure 23 Steps of deductive content analysis (Mayring et al., 2004).

begin the process by defining the research question and the theoretical background. The structuring content analysis aims to extract a certain structure from the material (Mayring et al., 2004). This structure categorizes the text components and extracts them systematically. The fundamental structuring dimensions must be exactly determined next. The dimensions used to structure the problem must be based on theory and relevant to the issue. These dimensions are typically further divided into specific features or values. Finally, the dimensions and values are combined to create a category system (Mayring et al., 2004).

Therefore, we defined categories for the evaluation. We have divided the research questions into three dimensions, namely *Design*, *Implementation* and *Application of the tool*. We further subdivided the design of the tool based on the categories for the creation of concept maps by Ruiz-Primo and Shavelson (1996): '*Task format*, *Response format* and *Evaluation format*. We subdivided the implementation into two categories: *Usability* and *Further functions*. We subdivided the Application of the tool into two categories covering

the main applications of concept maps in an educational context that we isolated in section 4: *Application as diagnosis* tool, and *Application as teaching and learning tool*. We assigned text components and anchor samples to the categories as follows:

- Design of the tool
    - Task format (Question 2); (line 16)
    - Response format (Questions 1, 5); (line 5)
    - Evaluation format (Questions 5, 5.1, 10); (line 76)
- Implementation
    - Usability (Questions 4, 6, 7, 9); (line 170)
    - Further functions (Question 10); (line 218)
- Application of the tool
    - Application as diagnosis tool (Questions 5, 5.1, 8, 8.1); (line 79)
    - Application as teaching and learning tool (Questions 3, 8, 8.1); (line 207)

The next step is the creation of Definition of the coding guideline (definitions, anchor examples and coding rules) (Mayring et al., 2004). Anchor samples help to identify the fitting category for content better. When there were problems of delineation between categories, we formulated rules. An example would be: To distinguish between the categories of *Evaluation format* and *Application as a diagnosis tool*, we categorized the benefits under *Application as a diagnosis tool* and the formal functionalities under *Evaluation format*.

Following that, Mayring et al. (2004) propose preliminary codings. We skipped a formal coding process and summarised the results in the categories since We only evaluated the contents and didn't evaluate the frequency with which the categories were mentioned. The frequency lacks useful information as only one teacher was interviewed.

We used a nominal category system for the process. We also added the information from our observations and the open discussions with the students. After completing 50% of the process, we reviewed the categories like Mayring et al. (2004) propose. We were satisfied, so we did not add any new ones or reduce them. Because of that, no final work-through was necessary. We did not repeat the coding process with a second person to avoid exceeding the scope of the work.

The following chapter presents the results. Afterwards, we will interpret the results like Mayring et al. (2004) proposes.

6.3 Results

This chapter overviews the research results, separated into categories. The evaluation contains the results from the interview, the reports of the students and our observations.

6.3.1 Task format

The teacher described the created maps as good. However, the teacher also mentioned that the task could be cognitively less challenging for the students than creating a mind map, where the concepts must be extracted from a text (line 16). On the other hand, the teacher saw the advantage that the concept maps can activate students easily because assistance is already given (line 28). The teacher noticed a potential benefit because the concepts provided a safety net (line 17). The teacher also mentioned an advantage in the

speed at which the maps can be created (line 19). The teacher said the students don't need much time to get used to the task (line 19).

The teacher also mentioned that it could be suitable for weaker students because the list of concepts can function like a roadmap of what is left to learn (line 29). In response to the question of where the tool could be used in a lesson, the teacher called the mapping process economic. However, the teacher thought it simplifies some complex information too much and would like to extend the mapping with more visual options for the propositions and concepts (line 16, 182). The teacher also preferred to extend the task format so the students could add some concepts independently (line 31). The teacher saw an advantage in differentiating the task's difficulty for each student. The fast students can add some of their terms to personalize the map further and better represent their knowledge (line 35, 221).

One student from the eighth grade answered the question if the tool is better to use than mind mapping or other mapping techniques they tried, that the tool enables a better temporal arrangement of events. One explained that knowledge can be memorized more quickly because the task forces the mapper to employ the knowledge. The students also mentioned that the list of concepts is helpful. One student specified that and said that the list of concepts helped to bring a structure to the map.

6.3.2 Response format

The teacher saw an advantage of digital concept mapping in that it is very motivating for the students because the students are so native to the usage of digital media (line 7). The teacher thought it was much more interesting for the students to do the mapping digitally (line 5). Digital mapping can also be more fun for the students (line 36). But it is also more practical because the students can correct mistakes much more easily than on paper. The teacher pointed out the difficulty of planning an analogue map and dividing the paper into sections. Digital mapping, on the other hand, has the advantage that it enables the movement of nodes and zooming in and out to use additional space (line 37). Generally speaking, the teacher sees the advantages of digital mapping in the easy haptic usage of the mapping part (line 38).

In response to the question of whether the tool can make the work of a teacher easier, the teacher mentioned the possibilities of remote learning. Remote learning can be enabled by the server-client structure (line 207). But the teacher also mentioned the problem of the answer format, that a basic condition for the application is always a sufficient number of devices (line 154).

In response to the question of where the tool can be applied in lessons, the teacher mentioned that the mapping with the tool is much less elaborate than with the paper version (line 207).

One eighth-grade student stated that digital mapping tools make it easier to move nodes than other mapping types, such as mind mapping. The students also mentioned that the option to reconnect and delete connections makes the mapping process much more pleasant than on paper. One student described the mapping as a much more enjoyable way to organize knowledge. Another student answered that the tool enables a good visualisation. They also highlighted that the media-supported task is very motivating. The students repeated multiple times that the tool helps to make the mapping process faster.

6.3.3 Evaluation Format

The teacher mentioned that the layout created with the tool is very clear (line 75). The teacher explained the nodes do not overlap, and the edges don't cross (line 76). The teacher described the layouts as structured and nearly symmetrical (line 76). The teacher described further that the layouts, when using the linking version, are perfect when the nodes move just a little so that you can see the changes, but the nodes stay approximately the same position (line 109).

Regarding which layout version holds the most significant value, the teacher answered that playing around between stability and quality happens automatically until the layout is pleasant (line 108). The teacher mentioned that the anchoring version wasn't nearly used because the linking part seemed much more intuitive without setting an anchor (line 111). However, the teacher mentioned the advantages of anchoring when comparing multiple maps (line 112). If the teacher would like some extensions to show average maps of students, the teacher replied that average values don't hold the correct information (line 244). The teacher said it is much more interesting to look at the maps of some specific students (line 245). The teacher sees a big part of the value of the concept maps in the option to talk about them with the class (line 246). To the question of scoring being an excellent addition to the tool, the teacher replied that it is impossible to map a whole class's knowledge to one number (line 247).

6.3.4 Usability

The teacher stated that the inclusion of the tool in the lessons is, after an introduction, possible without any problems (line 170).

The teacher said the students needed close to no help to get used to the tool (line 64). The teacher saw the need to introduce the tool in front of a class, but the teacher thought that the generation of students is so practised in using digital applications that they can use the tool easily (line 64). The teacher describes that the students tried to find the tool's limits relatively fast (line 65).

The teacher also thought that with a little bit of practice, the tool is easy to use for a teacher (lines 60, 121). The teacher stated that it would be possible to use the tool after an introduction and a lesson as a spectator (line 62). The only point where the teacher thought some more time would be necessary was the classes' setup and the GraphML files' opening (line 124). The teacher guessed learning this process would take about two to three hours (line 125).

One of the students from the eighth grade described the tool as good to use, with some small bugs. That the tool contains some minor bugs was mentioned multiple times. One bug stood out when we watched the students during the mapping process. The background was marked blue while drawing edges on the iPads the students used for the mapping. One student called the tool fast to understand. Another student described the login process as quick and easy. They also highlighted that the usage of the tool is very fast. One explained that the option to change the map quickly makes the mapping process very fast. The eighth and the ninth grades repeated the speed aspect multiple times. One student from the ninth grade mentioned that the usage is a question of training. The students felt much more prepared for the mapping. The students became faster with every mapping.

While spectating the mapping process, we had the same impression. The mapping process became smoother and smoother with every mapping. Overall, the students were able to get used to the controls fast.

6.3.5 Further functions

The teacher requested more options to visually separate concepts, such as using different shapes or colours (line 218). The teacher also asked for more options to separate the propositions, with some visually varying options (line 221). Further, the teacher asked to extend the task format so the students could add their concepts to the given list (line 35, 221). The teacher mentioned the potential for differentiated instruction to give faster students more options to extend the concept map (line 35, 221).

In addition, the teacher asked for the option for students to review their own concept maps in the web application to use them for learning purposes (line 228). The teacher also mentioned extending the tool so that the concepts can be used as flashcards with information about the concept on a second layer.

The students ask for the option to add their concepts. The students also asked for more options to design the different proportions and concepts with different colours and concepts. One student also asked for the option to change the size of the concepts. The need for more colours and shapes isn't very representative since the teacher asked a suggestive question before this answer. However, the wish for the option to add their concepts was repeated multiple times. They also wished for the option to review their own maps. These wishes were repeated in the eighth and ninth grades. One of the students asked for info boxes that could briefly explain the concepts.

6.3.6 Application as diagnostic tool

The teacher described the tool as helpful to see what a student could link to the rest of the map and which concepts the students couldn't link to the rest (lines 9, 78). The teacher proposed to repeat the mapping of a lesson with some distance to see how much the students can remember (line 79). The teacher mentioned an example from the lessons about the beginning of the First World War. Some of the dynamic concept maps viewed by the teacher had the problem that the concept "Balkan ein Pulverfass" wasn't connected to the rest of the map. The teacher mentioned that this concept is central, and the analysis helps to see the missing understanding of the concept (line 80). The teacher concludes if a central concept wasn't understood, the students didn't understand all other historical evolutions mentioned in the lesson (line 83). Later, in a separate talk, the teacher said that the aspect of the lesson had to be repeated. The teacher mentioned that another mapping with more distance would probably have contained some interesting evolutions. The teacher said the tool could be used about five to six times yearly.

One student from the eighth grade mentioned the tool helped to make their own learning advancement visible.

6.3.7 Application as teaching and learning tool

The teacher described that applying concept maps can help the students better understand a subject (lines 10, 96, 44). But the teacher also mentions that it works for some students better than for others (line 44). The teacher also mentioned the application for large blocks like industrialisation that continue for several lessons (line 93). The teacher proposed mapping with a reduced pool of concepts during each individual lesson and mapping with all concepts together in a final lesson (line 84). This way, the students could combine the parts from different lessons into one big picture (line 89). The teacher mentioned that that could help to do more complex considerations like the question of who

profited in the end from the industrialisation or how the politics or economy could have influenced the industrialisation's outcome (line 100).

The teacher saw an application of the tool in substitution lessons to give students a task that can be analysed from afar (line 207). In the next lesson, the concept maps can be used to repeat the learned contents (line 209). The teacher also mentions the same use in a homework scenario (line 209).

The teacher also describes the application during exam preparation. The list of concepts contains the central terms the students should know for the exam, and the students can use the tool to structure the knowledge and use the concept map to test themselves. The students can later use the maps they created during the lessons to check their understanding and what parts they must repeat (lines 46, 158). Reviewing the created maps can help them to remember the connections they drew earlier. If students see their map and recognize they knew a connection earlier, it can be motivating to see that they understood it earlier (line 161). According to the teacher, this can be much more motivation than reading the exact text for the fifth time (line 161). The teacher also mentioned that applying just once a year isn't worth it. The teacher said that students' dialogue about their concept maps could help them learn a lot (line 131). The teacher also describes that the tool can help students to see how they learn (line 9).

An eighth and ninth-grade student mentioned that the tool helps understand subjects. Another student described that the knowledge stays in the head because of the visual representation created. One student mentioned that the tool helps with the sorting of knowledge.

Regarding whether they can imagine using the tool in other school subjects, the students replied that they can imagine the application primarily in the humanities and chemistry.

6.4 Evaluation

6.4.1 Design

As mentioned earlier, the task, response and evaluation format are integral to creating a concept map. Since all three formats are set when using the tool, they must lead to concept maps to help a teacher analyse the students' knowledge (Ruiz-Primo and Shavelson, 1996). Because of that, they are a central part of the question of whether the tool is applicable in an educational context.

We chose a task format that is quite restrictive since the mapper can only use concepts from a restrictive list of concepts. When a list of concepts is given, the concept maps tend to have more cross-connections. The idea was that the format could lead to better and more explanatory concept maps than free mapping (Cañas et al., 2012) and make the mapping process faster. It seems true since the teacher described the resulting maps as good. The list of concepts can make the mapping easier for weaker mappers. However, the restrictive task format leads to a loss of information.

In addition, according to the teacher, the task format brings the advantage that the list of concepts can function like a safety net. (Cañas et al., 2012) mentioned in his work that a list of concepts can help the mapper to lose the fear in front of an empty paper. The students already have a starting point. The teacher's argument that the task could be less challenging than an open task format can be supported since a big step of a free creation task is skipped, but the part that leads to the most learning during the mapping process is building is the creation of the propositions (Cañas et al., 2012). The restrictive list of concepts can determine a student's knowledge (Cañas et al., 2012). In this context,

it makes sense to use the method to evaluate the state of knowledge of the students. However, the teacher and the students ask to give the students the option to add extra concepts to the map. That could reduce the degree of restrictiveness and give the students more freedom to create maps representing their state of knowledge. The option could allow faster students some more options to extend the concept map. This could improve the integration of the lessons.

We also added the restriction that the mapper can't add labels to the propositions. But the task is to think of one but omit it. This can make the mapping process a lot faster. The teacher mentioned some concerns that with the restrictions of the context, the task loses too much complexity. This less complex is a sign of less learning, according to Krabbe (2014). The teacher asked to comprehend this for the options to change the appearance of the proportions to add more complexity. We knew that we reduced the complexity of the task in comparison to a free mapping task, but the chosen task format led to a much faster and more convenient mapping. The students and the teacher support this thesis. The teacher, as well as multiple students, mention that the mapping process is fast. But the creation of the propositions is the aspect that leads to the most learning, and this process still happens even tho the labels aren't stored.

Overall, the teacher and the students seem to like the task format. The task format seems to have helped with the map's structure since one student stated that the list of concepts helped to bring a structure into the map.

For the response format, we chose a computer-based mapping with a client-server structure as Krabbe (2014) proposed. The teacher and students agreed that the digital concept mapping is very motivating. The teacher and students also agreed that it is much more practical because the students can correct mistakes much more easily than on paper. The students mentioned that the digital tool makes it much easier to move the nodes around, and it makes the whole process more pleasant. According to (Schanze and Grüß-Niehaus, 2008), computer-based mapping simplifies the revision of concept maps. As mentioned earlier, the teacher mentioned that the concept maps created with the tool are good. The response format could also influence this. Krabbe (2014) mentions that computer-based mapping leads to more complex concept maps. Another advantage is that computer-based mapping enables good visualisation and makes mapping faster. A downside mentioned by the teacher and in research is the availability of the devices. The teacher mentioned that digital mapping seemed to only have positive aspects in our testing, except for the availability of the devices.

The teacher seemed convinced by the concept of visual analysis. When the teacher was asked if MIDI maps or a scoring system would improve the tool, the teacher denied it. The teacher mentioned that the knowledge of a student can't be reduced to a number.

To support the visual analysis, we implemented the layout function. If the quality factor is high enough, the layout algorithm should produce good layouts according to Mader (2014). The teacher mentioned that the layout algorithm produces very clean layouts. The teacher specified that when explaining that the nodes don't overlap and the edges only have a few crossings. The teacher also mentioned that the maps created in the tool look structured and symmetrical. This checks three of the five aesthetic criteria for a good layout by Bennett et al. (2007). The only two conditions not mentioned are that all edges should have the same length, and the vertices should be distributed well over the drawing area. That doesn't necessarily mean the conditions aren't fulfilled but aren't mentioned in the interview. The teacher described the perfect layout for the dynamic concept map with the two factors that the concept should move just a little bit, but the position of the nodes should be quite stable. It seems the teacher could create a visualisation with good

individual layouts and preserve a mental map for the teacher.

The teacher described finding the perfect trade-off between quality and stability nearly happened automatically. The teacher explained that the best trade-off is found eventually after some toying around. This can only be applied to the linking version since the teacher said the anchoring part wasn't used. The teacher said it is much more interesting to look at the maps of some specific students. The linking version's usage makes sense since the teacher didn't compare different students' concept maps. Spener (2017) has shown in his work that the linking version can bring an advantage when comparing different instances of a concept map. The teacher seemed happy with visualising the concept maps with the linking algorithm. The teacher didn't like the extra step to create a visualisation with an anchor. However, the teacher seems to have realized the advantage the anchoring algorithm could bring since the teacher mentioned the advantage the anchoring algorithm could have when comparing multiple maps. Maybe it would be necessary to create an option to make the anchoring process easier for the analyser. An option could be to use an aggregation version like Mader (2014) proposed. This way, the analyser doesn't have to consider the anchoring layout.

Overall, the design, response and evaluation format choices work well in the tested scenario. The biggest problem for the teacher seemed to be the lack of complexity of the task. We could implement some options to improve the tool to give the analyser more options to increase the complexity of the task.

6.4.2 Implementation

The students and the teacher seemed to have few problems getting used to the tool. The teacher thought the students needed an introduction by an expert but could use the tool after that without significant issues. The teacher believed that the students had no problems using the tool because the students were so practised in using digital applications. This matches our expectation that the students can get used to the tool relatively fast. The students also approved that the tool is quick and easy to use. One student even highlighted the login. We tried to design the login quickly and efficiently so no further time is consumed with forgotten passwords and account creation. The student seemed to have found some bugs during the tool's usage. One problem was explicitly tied to the use of iPads. Since one of the objectives for the agency was to make it available on all sorts of devices, we have to fix this problem in the future.

The teacher seemed to be able to use the tool without much of a problem. The teacher states that using the tool to its full potential after an introduction and a lesson as a spectator would be possible. The teacher needs more training to set up classes and open the GraphML files for analysis. Overall, the teacher guessed the time investment to get used to the tool at about three hours. This is an amount of time that could be provided in teacher training. Overall, we are quite happy with the performance of the tool's usability. Except for some minor bugs, the teacher and the students seemed to have no problems using the tool.

The teacher and the students asked for some additional functions. We already talked about the further options to make the task more complex and the option to add additional concepts. One request by the students and the teacher was to allow them to revisit their maps. We agree that the option could help improve the students' learning. The learning advancement could improve the students' perception of the teaching (Pankratius, 1990). On the other hand, adding this function would bring some problems with the core structure of the tool. If the students can visit their old maps, hiding their creations behind a login

becomes necessary. Adding a login could complicate the tool's usage for the teacher. We must find an option that keeps the login simple and fast and enables the students to review their maps.

The teacher and one student also mentioned using the tool more to acquire knowledge and give the option to add descriptions to the concepts. This is a function the Cmap tool supports. The idea of the tool is to use the tool for the structuring of knowledge and not the acquisition of knowledge.

Overall, the design and implementation of the tool seem to support the usage of the tool in an educational context. Some minor bugs have to be fixed, and we have to find a good way to let the students review the maps without making the tool's usage more complicated in the future.

6.4.3 Application

When looking at the concept maps created with the tool as a diagnostic tool, the teacher described that the tool helped to see which concepts were connected by the students and which weren't. This knowledge can help teachers improve their teachers and fill the students' knowledge gaps. The teacher explained this by describing an example from the block about the First World War. The teacher saw during the analysis that one node wasn't connected enough in the reviewed dynamic concept maps. The teacher found a missing connection in the maps of multiple students and concluded the class's level of knowledge. Following that, the teacher decided to repeat a topic. This way, the teacher decided to adjust the further orientation of the lesson according to the results.

The teacher also mentioned that revisiting a subject with some temporal distance could be interesting. This way, it is possible for the teacher to see how much the students still know and refresh their knowledge. When testing not only the knowledge of the students but the evolution of knowledge, the advantage of dynamic concept maps is shown. The teacher can see what the students forgot and what they never understood. Based on this knowledge, the teacher can decide whether to repeat a whole segment or remind the students. This example shows that the tool can use dynamic concept maps as a diagnostic tool.

The biggest question when looking at the created concept maps as a learning tool is if the concept maps induce higher level learning according to the taxonomy of Bloom (1956). The teacher seemed convinced that the tool helped the students get a deeper understanding of the subject represented on the map. The students seem to share this view. They mentioned that the tool helps with the knowledge of subjects. One student described that the tool helps with the sorting of knowledge. Knowledge sorting can be placed higher in the taxonomy of Bloom (1956) than memorisation. The teacher proposes using the tool during big blocks, like industrialisation, to help the students put the information of the single lessons together to a bigger picture. This way, the students can get a deeper understanding of a subject. The teacher mentions that it can help the students to do deeper considerations. It seems like the teacher sees the potential contained in the tool to help students dive deeper into a subject. The teacher also mentioned that the created concept maps can show students how they learn. This can be essential knowledge since learning how to learn is important.

The teacher sees an application of the tool for substitution lessons or homework so the results can be analysed from afar. This wouldn't be possible without the client-server structure. According to Stracke (2004), concept maps can be used as roadmaps for a subject. The teacher also described the application for the exam preparation. The tool

can serve the students as a roadmap, what they still have to learn and what they may have forgotten. The concept maps can also serve as a summary. Stracke (2004) mentions that concept maps as summaries have the advantage of being less complex than a text. The teacher thinks that the tool can motivate the students because reading the same text multiple times can be frustrating for a student.

The teacher also mentions that students' dialogue about their concept maps can help them better understand a subject. Kinchin (2014) described that the dialogue during the creation of concept maps can help students with their learning.

Overall, the teacher mentions multiple valuable applications for the maps created with the tool that enable deeper learning. In research, concept maps are applied in science in an educational context. Noteworthy is also the potential mentioned application in e-learning scenarios.

The students prefer an application in humanities. They see the concept maps could positively impact chemistry but think the better applications are in humanities. Some further studies on how concept maps could improve humanities could bring interesting results. Overall, the teacher and students see the potential contained in the application of the tool to create concept maps to enable a higher level of learning.

The application of the toll as a learning, teaching, and diagnostic tool seems to work quite well. The example from the block about the First World War showed quite nicely the positive impact the tool can have. There is some more potential. For example, the teacher didn't mention the option to use the tool to evaluate the student's prior knowledge.

6.4.4 Answering the research question

To answer whether the tool can bring benefits in an educational context, we tested if the design and implementation of the tool supports the application in an educational context and if the concept maps created with the tool can be used as teaching, learning and evaluation tools. The tool's design and implementation seem to apply in an educational context. The response and evaluation format supports the application in an educational context well. The teacher prefers the analysis using visual analysis over scoring options. The economical and efficient design of the task format helps to include the mapping in lessons. One view design decision that must be rethought is the simple task. It will need further testing with more teachers if a task with a higher complexity is necessary. Another decision that has to be rethought is the option for the mappers to review their own concept maps. The problem is that we would have to make the login for the students more complex. However, the research results have shown that the option for retrieving the concept maps is important. Another improvement for the future is the enhancement of the anchoring layout part. The anchor selection should be easier to make the usage more attractive.

The research has shown that the created concept maps can fulfil multiple purposes. The concept maps can fulfil the role of a diagnostic tool. The example lesson about the beginning of the First World War showed this. The teacher could analyse the students' misconceptions and adjust the further lessons. The students felt the tool helped them better understand the subject. Therefore, the concept maps created with the tool helped the students with a higher level of learning. The teacher also mentions the potential to encourage higher-level learning. The tool helps analyse the state and evolution of the student's knowledge. Because of that, the tool can help the teacher to adapt their lessons in a way that supports the students as well as possible. Therefore, the tool can benefit the higher level of learning of students and the diagnostic abilities of teachers.

7 Discussion

This thesis aimed to provide a tool to create, collect and visualise dynamic concept maps. Novak created concept maps for use in science lessons, but they are not frequently utilised in classes, according to Kinchin (2001). A fundamental problem with applying concept maps in an educational context is that it is time-consuming for the teachers. Creating the maps takes a lot of time during lessons, and evaluating the maps takes time for the teacher outside the classroom. The main objective of the tool was to make it applicable in an educational context. Therefore, the tool was designed to make the maps' creation, collection and evaluation as easy and fast as possible. The concept maps should enable a higher level of learning for the mapper and allow an assessment that helps the analyser draw as much information as possible from the dynamic concept maps. We enabled dynamic concept maps to analyse both the final representation and the evolution of knowledge. Since a qualitative analysis of the created maps can help to retrieve more information from a concept map than quantitative analysis, the tool presented in this work supports the qualitative analysis. Therefore, the tool uses the mixed layout algorithm to make the analysis as easy and fast as possible. We presented different existing tools for the creation of concept maps. Only tools designed for analysing graphs and networks support a function for the layout of dynamic graphs. Since those tools are intended for use by experts, those tools aren't easy to use for teachers. Another downside of tools for analysing networks is that it is time-consuming to collect the dynamic concept maps of multiple students. The tool presented in this work makes the process much easier using a client-server structure, allowing the analyser to fetch all dynamic concept maps of a class from a server.

We have shown in the research part of this work that the design and implementation of the tool are suitable for application in an educational context. However, we also have seen that future changes are necessary to improve the tool further. The interviewed teacher asked for a more complex task format. It will need further testing with more teachers if a task with a higher complexity is necessary. Another design decision that has to be rethought is the option for the mappers to review their concept maps. The problem is that we would have to make the login for the students more complex. However, the research results have shown that an option for the students to retrieve their concept maps is important. Reviewing the concept maps could help the learning of the students and improve their perception of the teaching. Another function that could be added in the future is the option for the student to generate a layout during the mapping process. This could help the students to get more structure into their maps.

The teacher tested the tool mainly to compare the different instances of a dynamic concept map. As the work of Spener (2017) has shown, a layout with a higher factor of liking layout can support the comparison better. A more anchoring-focused layout could be more helpful for comparing different dynamic concept maps. The extra step necessary to use the anchoring layout seemed to make it unattractive for the teacher, even though the teacher recognised the advantage a more anchoring-focused layout could bring. The anchoring function doesn't seem very attractive at the moment. Spener (2017) already proposed to use a vertical aggregation of the concept maps to improve the anchoring layout. Since this way, it isn't necessary any more to create an anchor layout manually. It could be more attractive for evaluation in the future. Another option that could be implemented to improve the comparison of different dynamic concept maps with an expert map is the colouring of edges according to whether an expert drew this line or not.

We have shown that the dynamic concept maps created with the tool can bring advantages in an educational context. The concept maps can help students with a higher level

of learning and can help teachers with the evaluation of the state and evolution of knowledge of their students. Weinert (2000) stated that one of the main four competencies of a teacher is diagnostic competence since teachers can adapt their teaching based on the information gained during the evaluation.

The coronavirus pandemic has shown interaction between the teacher and students from afar can be difficult. Bad connections, microphones and cameras make it hard for teachers to evaluate the state of knowledge of their students. We have shown that the client-server structure has the potential to help the teacher by evaluating the state and evolution of a student's knowledge from afar. This is an ability that can become more and more valuable with an evolution towards more e-learning. In an e-learning scenario, the application of the tool for self-analysis seems possible. Therefore, the tool's option to review the maps seems especially important.

The study presented in this work can only give hints with the small sample size of interviewed teachers. In addition, structured research with students wasn't possible. Because of that, the study presented in this work can only give hints to answer the research question. Therefore, the presented tool has to be tested further in the future. To prove the concept maps created with the tool can help the students with a higher level of learning, a quantitative study with students from different grades would be necessary. To evaluate if the tool can make the usage of concept maps in an educational context more attractive for teachers, it would be required to test the tool with a higher number of different teachers from different subjects. Such a study could also bring interesting insight into whether the tool can get more benefits in humanities or science subjects. Until this point, studies focus on applying concept maps in science subjects. Spener (2017) mentioned in his work the option to further evaluate the impact of the layouts on the analysis speed; a study using eye tracking could bring insight. A study using eye tracking could help assess the analysis's advantage.

To further assess the advantages of the visual analysis using layout, the tool could be tested in direct comparison to a tool that supports automated evaluation techniques like scoring.

As we have shown, there is a lot of potential in the idea of a tool optimised for creating, collecting and evaluating dynamic concept maps in an educational context, but there is still much work.

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8 Appendix

8.1 Interview guideline

1   Welche Vorteile bietet die Nutzung des Programms und das digitale Erstellen von Concept Maps für die SuS?

2   Wie würden Sie die Methode Concept Maps mit vorgegebenen Knoten im Vergleich zu anderen Methoden wie einem Zeitstrahl oder Mindmaps bewerten?

3   Inwiefern glauben Sie hilft die Methode Concept Maps den SuS bei einem tieferen Verständnis der Unterrichtsinhalte?

4   Wie viel Unterstützung haben die SuS Ihrem Gefühl nach benötigt, um das Programm nutzen zu können?

5   Inwiefern hilft Ihnen das Tool beim Einschätzen des Leistungsstandes der Schüler?

     5.1   Welches layout Verfahren bietet den größten Mehrwert?

6   Wie viel Unterstützung würden Sie benötigen, um das Programm zu nutzen?

7   Inwiefern würde es für Sie eine Arbeitserleichterung darstellen?

8   Inwiefern lässt sich die Nutzung des Tools in den Unterricht eingliedern?

     8.1   In welcher Phase des Unterrichts kann das tool Anwendung finden?

9   Wie oft würden Sie das Programm im Unterricht nutzen?

10   Welche weiteren Funktionen würden Sie sich wünschen?

8.2 Interview

1 **Interviewer:** Vielen Dank für die Teilnahme an diesem Interview. Zuerst werde ich einige
2 Fragen dazu stellen, wie die Schüler mit der Nutzung des Tools klargekommen sind und
3 dann zu Ihren Erfahrungen als Lehrperson mit dem Tool.
4 **Lehrkraft:** Ok.
5 **Interviewer:** Dann die erste Frage: Welche Vorteile bietet die Nutzung des Programms
6 und das digitale Erstellen von Concept maps für die Schülerinnen und Schüler?
7 **Interviewer:** Es ist spannend, auf jeden Fall. Es ist ein Zugang, den sie zu Stoff finden
8 können, wenn es ihnen selber gelingt diesen, über etwas, was ihnen definitiv näher liegt,
9 nämlich digitale Hilfsmittel zu finden. Einen weiteren Vorteil würde ich darin sehen, wenn
10 man es in diesen Schleifen macht, in denen sie es durchgeführt haben, dass Schüler wirklich
11 sehen, wie sich Dinge langsam vernetzen und sich so einzelne Begrifflichkeiten zueinan-
12 der in Beziehung setzen lassen bzw. sie erkennen können, wie Beziehungen entstehen.
13 Es zeigt die Veränderung, was der Schüler an Wissen ansammelt und ein Verständnis für
14 dieses Wissen hat. Es ist sicher spannender als es auf einem Blatt Papier zu machen, vor
15 allen Dingen weil die Korrektur leichter möglich ist, wenn ich etwas falsch gemacht habe.
16 Es fordert sie unter Umständen nicht so extrem kognitiv heraus, wie bei einer Mindmap,
17 bei der Sie die Formulierungen und Begrifflichkeiten selber erstellen müssen. Sie haben
18 sozusagen ein leichtes Sicherheitsnetz dadurch, dass Formulierungen schon vorgegeben
19 sind. Es ist schnell umsetzbar. Es ist nichts, bei dem sie sich erst lange über Arbeit-
20 sanweisungen in etwas einfinden müssen. Und damit sehen sie eine Veränderung oder
21 einen Fortschritt deutlich schneller. Sprich auch nach einer Stunde oder Doppelstunde. Je
22 nachdem wie man es nutzt und wie viele Wiederholungen man macht, ist für einen Schüler
23 schneller etwas erkennbar wie bei einer Mindmap.
24 **Interviewer:** Vielen Dank, das war ja schon sehr ausführlich. Wie würden Sie die Methode

25 Concept maps mit vorgegebenen Knoten im Vergleich zu anderen Methoden, wie einem
26 Zeitstrahl oder einer Mindmap, bewerten? Sie haben das gerade ja auch schon ein wenig
27 angesprochen.

28 **Lehrkraft:** Also ich finde, es ist schüleraktivierender, weil im Prinzip bereits eine Hilfestel-
29 lung gegeben ist. Es ist dann auch für schwächere Schüler so, dass diese sehen, was ist
30 denn noch an Restpaket übrig, dass ich eigentlich erledigen müsste. Das heißt, es ist so
31 die Quantität auch abschätzbar. Wie gesagt, ich fände es ganz schön, wenn hinzukäme,
32 dass man selber noch lehre Punkte hätte, die man füllen kann. Ich glaube, das wäre eine
33 gute Herausforderung für die schnellen, vielleicht auch kognitiv mehr leistenden Schüler.
34 Also so dass der Schüler das Gefühl hat, wenn mir da noch etwas Wichtiges einfällt, kann
35 ich selber etwas ergänzen. Das könnte im positiven Sinne so eine Herausforderung oder
36 Challenge sein.

37 Bei einer Mindmap oder einem Zeitstrahl weiß der Schüler oft nicht wie er das Blatt ein-
38 teilen soll. Hier ist der Vorteil, die Größe ist nicht gegeben. Ich kann reinzoomen, um
39 die Knoten zu lesen, aber auch wieder herauszoomen. Auch einfach durch diese haptisch
40 parallele Handhabung des Ganzen ist da einiges geschickter machbar als auf Papier. Ich
41 finde die Concept maps die entstanden sind sehr gut.

42 **Interviewer:** Vielen Dank. Inwiefern glauben Sie hilft die Methode Concept Maps den SuS
43 ein tieferes Verständnis der Unterrichtsinhalte zu erlangen?

44 **Lehrkraft:** Ich glaube schon, dass es das tut, aber sicher, wie bei jeder Methode, unter-
45 schiedlich stark je nach Schüler, Fähigkeiten und Interessenslage. Aber ich glaube, wenn
46 sie später auch hinterher mal so eine ausgedruckte Concept map hätten, würde es den
47 Schüler helfen es wie eine Oberflächenebene zu nutzen und wenn sie in der Vorbereitung
48 für etwas anderes sind wie auf einer zweiten Ebene da unten drunter, eine längere Erk-
49 lärung hätten. Das wäre wie so eine Selbstkontrolle: Kann ich zu dem Begriff etwas sagen
50 und wenn nicht was ist, so zu sagen meine Flashcard, die dahinter liegt, auf der ich das
51 Wissen nachlesen könnte. In dem Sinne wäre es auch ein Selbst-Kontrolle-Instrument in
52 der Vorbereitung auf eine Klassenarbeit oder so etwas. Dafür glaube, ich könnte es echt
53 etwas bringen.

54 Interviewer: Ok ja als Selbstkontrolle ist es sicher auch sehr gut anwendbar. Dafür können
55 sicher auch noch die Funktion kommen, dass Schüler ihre Maps noch einmal anschauen
56 könne.

57 **Lehrkraft:** Genau

58 **Interviewer:** Was war Ihr Gefühl, wie viel Unterstützung haben die SuS benötigt, um das
59 Programm nutzen zu können?

60 **Lehrkraft:** Recht wenig. Es war sicher gut, das Programm mit jemanden einzuführen, der
61 mit dem Programm und der Idee dahinter bekannt und vertraut ist. Das macht sicherlich
62 Sinn. Wenn man es als Lehrer zwei oder drei Mal gesehen hat, ist es auch einfach es selber
63 durchzuführen. Ich glaube, die heutige Schülergeneration ist durch Medien sehr affin zu
64 der Nutzung von solchen Sachen. Es macht ihnen so Spaß, dass ich finde, das war recht
65 schnell anwendbar und umwendbar. Also sie sind eher sogar an die Grenzen des Machbaren
66 gestoßen und konnten gut formulieren, was sie sich anderes wünschen würden. Also von
67 dem her sehe ich keine Berührungsängste. Das war deutlich erkennbar. Spaß an der Sache
68 und eigentlich auch das Mitdenken, was bräuchte ich denn jetzt noch, damit es auch für
69 mich selber gewinnbringender ist. Insofern zeigt mir des, dass da keine Hemmschwelle da
70 ist.

71 **Interviewer:** Das Gefühl hatte ich auch: Erst einmal die Grenzen austesten, was ist über-
72 haupt möglich. Kommen wir jetzt noch ein wenig zu der Sicht aus Lehrerperspektive.

73 Inwiefern hilft Ihnen das Tool beim Einschätzen des Leistungsstandes der Schüler? Gerade,

74 wenn man sich den Lernprozess anschauen kann.

75 **Lehrperson:** Die erstellten Concept maps sind nach dem Layouting sehr übersichtlich. Die
76 Knoten überlappen nicht und es gibt wenige Überschneidungen der Verbindungen. Die
77 Layouts sehen strukturiert und fast symmetrisch aus.

78 Im Hinblick auf die einzelne Stunde sieht man, was konnten sie verknüpfen und was nicht.
79 Wo könnte oder müsste man noch einmal, bezogen auf eine einzelne Einheit, noch einmal
80 etwas nachliefern oder nachschieben. Je nachdem, wenn etwas sehr zentral ist, dass sie
81 nicht einsortieren konnten. Wie hier dieser Begriff "Balkan ein Pulverfass". Was ja schon
82 etwas Zentrales ist. Wenn ich das nicht verstanden habe, verstehe ich auch die ganzen
83 anderen historischen Entwicklungen nicht. Also dafür könnte es für einen als Lehrer relativ
84 spannend sein. Spannend fände ich es auch noch, wenn man jetzt als Lehrer noch sagen
85 könnte: Ich mache jetzt noch mit dieser Minieinheit die Einheit fertig und werfe es dann
86 noch einmal alles rein und vergleiche, was nach drei Wochen noch da ist. Ich glaube, dann
87 wäre noch einmal verifizierbar, wie viel ist wirklich hängen geblieben. Dass während der
88 Doppelstunde Dinge da sind, die sich verknüpfen lassen, ist spannend. Spannender wäre
89 noch, mit einem gewissen Abstand darauf zu gucken und es in den größeren Kontext noch
90 einzuordnen.

91 **Interviewer:** Das ist sicherlich auch eine ganz gute Sache, die man noch öfter im Jahr
92 machen kann.

93 **Lehrkraft:** Oder ich denke an so eine lange Einheit wie Industrialisierung, die sich ja sehr,
94 sehr lange zieht. Und dann fangen sie da an mit England und allem und dann kommt
95 irgendwann Deutschland, was ja fast 80 Jahre versetzt zu England passiert. Dann machen
96 sie die Auswirkungen, dann kommt die ganze Arbeiterbewegung und das ganze Thema
97 soziale Frage. Und ich glaube, wenn man da am Ende noch einmal es in einer Gesamtein-
98 heit macht, wenn man es an verschiedenen Stellen schon einmal gemacht hat, mit den
99 einzelnen Teilaspekten, dann noch einmal alle Begriffe in einen Topf wirft und sagt: So
100 jetzt versucht mal eine Bewertung zu machen in der Summe. Also für wen war es jetzt
101 wirklich gut? Für wen war es nicht gut? Was taucht wann, wo, und wie auf? An welchen
102 Stellschrauben hätte Politik oder Wirtschaft eingreifen können/sollen/müssen? Also um
103 damit zu einer Bewertungsstruktur zu kommen. Dann glaube, ich wäre es noch einmal
104 ganz spannend. Aber das ist dann sicher auch sehr aufwendig.

105 **Interviewer:** Sie haben ja ein wenig mit den verschiedenen Layoutverfahren und den Ver-
106 hältnissen herumprobiert. Welches Layoutverfahren bietet denn Ihrer Meinung nach den
107 größten Mehrwert?

108 **Lehrkraft:** Puh, das Herumspielen zwischen der Stabilität und Qualität passiert fast au-
109 tomatisch, zwei oder drei Mal, bis man zufrieden ist. Wenn die Knoten sich ein wenig
110 bewegen, um die Veränderung zu zeigen, aber die Positionen ungefähr gleich bleiben, ist
111 es perfekt. Die andere Variante habe ich kaum getestet, weil die Linkingvariante sehr intu-
112 itiv ist und keinen weiteren Schritt benötigt. Aber ich könnte mir vorstellen, beim Vergleich
113 von Maps von mehreren Personen oder allgemein, wenn man noch mehr Maps hat, kann
114 das hilfreich sein. Der Prozess erscheint mir sehr aufwendig, um kurz die Maps von zwei
115 oder drei Personen anzuschauen und diese als Referenz zu nehmen.

116 **Interviewer:** Wie viel Unterstützung würden Sie benötigen, um das Programm so nutzen
117 zu können, wie Sie es beschrieben haben?

118 **Lehrkraft:** Ich als Lehrer?

119 **Interviewer:** Ja

120 Sie haben ja auch das Auswerten gesehen und getestet.

121 **Lehrkraft:** Mhm ja. Also in Bezug auf allein die Tatsache es zu nutzen gar nicht so viel
122 Zeit. Da ist glaube ich, wenn es einmal eingeführt ist, ok. Es ein- oder zweimal mitzuer-

123 leben und zu sehen was mache ich, das wäre gut. Ich glaube, wofür ich persönlich eher
124 die Zeit noch bräuchte, wäre: Wie lege ich die Schülernamen an und wie speichere ich die
125 Dateien, damit ich die Zip-Datei bekomme. Wie schaue ich das nachher an, wie stelle,
126 ich die Parameter ein? Das wäre vielleicht noch einmal ein Aufwand von - ich weiß nicht
127 - vielleicht zwei Zeitstunden. Gegebenenfalls drei Zeitstunden. Es ist, denke ich, wie bei
128 allem, man muss es dann halt regelmäßig auch mal probieren und machen, um zu ver-
129 stehen wie es funktioniert. Und diese Punkte, wie ich sie benenne und die Schülernamen
130 setze, bräuchte ich nochmal eine Einführung. Aber ich glaube, der Zeitaufwand ist echt
131 absehbar. Und was ich glaube, was sich nicht lohnt, ist es einmal im Schuljahr zu machen
132 und dann liegenzulassen.
133 **Interviewer:** Das lohnt sich wahrscheinlich nicht.
134 **Lehrkraft:** Das ist sehr ineffektiv, weil dann fängt man jedes Mahl bei null an.
135 **Interviewer:** Das wäre auch für die Schüler nicht so einfach. Ich hatte das Gefühl, man
136 hat schon gemerkt, dass sie dazu gelernt haben.
137 **Lehrkraft:** Genau das Gefühl hatte ich auch.
138 Interviewer: Warum kann das Programm eine Arbeitserleichterung für eine Lehrkraft
139 darstellen?

<center>Pause</center>

140 **Lehrkraft:** Ich überlege, gerade.

<center>Pause</center>

141 Spannende Arbeitserleichterung? Also ich glaube in dem Moment, in dem ich schnell mit
142 Schülern, z.B. für eine Auswertung im Unterricht auf die fertig erstellten Concept maps,
143 wie sie vom Schüler dann kommen, anschauen könnte, könnte es eine Arbeitserleichterung
144 sein bei der Auswertung von Arbeitsphasen und dem Ergebnis. Weil es da dann manchmal
145 lang dauert, bis man Lösungsvorschläge mitschreibt vom Schüler und eine Mindmap an
146 der Tafel zeichnet. Insofern wäre es eine Arbeitserleichterung an dem Punkt. Also das
147 schnelle Abrufen können. Ich überlege gerade eher in eine andere Richtung. Könnte es
148 für Stunden, wo man als Fachlehrer nicht da ist, man aber für die Schüler will, dass sie
149 trotzdem etwas arbeiten und Spaß haben geeignet sein? Da könnte es eine Erleichterung
150 sein, statt nur trögen Aufgaben, Quellentextanalysen oder Sonstigem zu stellen, um sie
151 wirklich auch ein bisschen zu motivieren, aus der Ferne in gewissem Maße: Und Ihr erstellt
152 diese Concept Maps und ich schaue die mir an. Dann sprechen wir über diese und machen
153 eine gesamte kurze Wiederholung. Das wäre eine Form der Arbeitserleichterung, setzt
154 aber die technische Möglichkeit voraus, dass Geräte in entsprechender Anzahl verfügbar
155 sind. Zumindest so, dass sie es in Kleingruppen machen könnten. Bei einer Klasse mit
156 dreißig braucht es dann sieben bis acht Geräte, die dann verlässlich da wären.
157 Eine Arbeitserleichterung vielleicht hinsichtlich einer Unterstützung zu liefern für die Vor-
158 bereitungen von Klassenarbeiten. Also indem man den Schülern sagt, das sind so die
159 Schlag- und Kernworte, die du können musst. Die den Schülern nochmal zu geben und
160 diese selber nochmal die Möglichkeit haben zu schauen, inwiefern kann er, die selber ver-
161 netzen. Es ist motivierender als ihm nur eine Liste zu geben, vor der er ziemlich frustriert
162 sitzt. Auch da holt der spielerische Aspekt sie woanders ab. Ansonsten im Unterrichtsall-
163 tag als Erleichterung seh ich es nicht konkret. Ich würde es als eine Bereicherung sehen,
164 mir eine weitere Möglichkeit zu bieten.
165 **Interviewer:** Sie meinen, für die Klausurvorbereitung könnte es Sinn machen, ihnen noch
166 einmal die Concept map zu geben. Nach dem Motto: weißt du noch …
167 **Lehrkraft:** Genau so könnte ich mir das vorstellen.
168 **Interviewer:** Inwiefern lässt sich die Nutzung in den Unterricht eingliedern, auch vom
169 Zeitaufwand?

170 Ich glaube, wenn man als Lehrer den Zugang zum Material problemlos hat und wenn man
171 dann mal verstanden hat, wie man das vorher vorbereiten muss und was hinterher noch
172 getan werden muss, dann ist es eine sehr unaufwändige Geschichte. Und wie gesagt ich
173 kenne Concept maps aus der Papierform, mit solchen Moderationskarten in verschiedenen
174 Formen und Farben und wo man erst die Begriffe noch aus dem Material ziehen muss.
175 Was aufwendig ist, man muss erst einmal hirnen muss, welche Begriffe brauche ich. Ich
176 muss erst einmal selber hirnen und mich durch die Ebenen und Strukturen selber denken.
177 Und dann werde ich das Problem haben, wenn ich es aufgeklebt habe auf einer Flipchart
178 und es bewegen muss, dass es aufwendig ist. So ist es eigentlich schon ökonomisch unter
179 diesem Gesichtspunkt.
180 **Interviewer:** Das war eins der Hauptziele, das Ganze so schnell und einfach wie möglich
181 für den Schüler zu halten.
182 **Lehrkraft:** Wie gesagt, ich bin ein Fan von ökonomisch und effizient und gleichzeitig und
183 das wäre vielleicht auch ein Stück, die Kritik: Momentan wäre es mir noch zu verein-
184 fachend. Nur eine Art Punkt, nur eine Farbe und nur eine Art Pfeile wäre mir zu wenig.
185 Gerade bei historisch komplexeren Thematiken, die vielschichtiger sind, wäre mir diese Art
186 zu vereinfachend. Und könnte, ich denke dafür ist aber auch der Lehrer da, um dem ent-
187 gegenzusteuern, dass ein schwacher Schüler meint, das ist wirklich so eindimensional. Also
188 da wäre auch der Kritikpunkt. Da würde eine Vielfalt von Pfeil, Form und Farbe Optionen
189 helfen die Komplexität abzubilden und dem Schüler helfen. Diese Entscheidung kann dem
190 Lehrer gegeben werden, wie viele Optionen soll der Schüler haben.
191 **Interviewer:** In welchen Phasen würden Sie das Tool im Unterricht einsetzen.
192 **Lehrkraft:** Wie gesagt, könnte ich mir den Einsatz am Anfang der Stunde vorstellen, um
193 die Schüler zu aktivieren. Später wäre der Einsatz auch möglich. Gerade, wenn es um das
194 Vertiefen des Gelernten geht. Ich glaube, es ist vom Thema und der Situation abhängig.
195 **Interviewer:** Wie oft würden Sie das Programm im Unterricht nutzen?
196 **Lehrkraft:** Ich glaube, es wäre themen- und einheitsabhängig. Aber ich sage mal, wenn
197 ich in den Phasen denke, in denen Schuljahre ablaufen. Üblicherweise liegen zwischen den
198 Ferienzeiten, Sommer bis Herbst, Herbst bis Winter liegen in der Regel irgendwo zwischen
199 5 und 7 Wochen. Einmal pro Phase oder auch zweimal wäre das gut einsetzbar. Eben, weil
200 es gut geht und unaufwändig ist, wenn man es hat. Oder dann auch gezielt mal zu sagen,
201 jetzt habe ich eine Einheit. Jetzt biete es sich an es auch einmal pro Woche einzusetzen,
202 weil da ein sehr spannender Verlauf abzubilden ist. Wenn ich sage, im Schnitt wäre das pro
203 Schuljahr so 5-6 Mal. Das wäre eine ganz interessante Perspektive, um den Leitungsstand
204 der schüler zu checken.
205 **Interviewer:** Könnten Sie sich auch vorstellen, das Mappen als Hausaufgabe zu geben. Die
206 Website ist ja offen erreichbar.
207 **Lehrkraft:** Klar, auch dafür wäre es durchaus möglich. Auch das andere, das ich vorhin
208 angesprochen hatte für eine Stunde Vertretungsstunde. Ich sage auch mal so, dann haben
209 die vielleicht eine Stundenplan-Optimierung, aber statt während der Vertretung, die Schüler
210 das hier machen zu lassen, machen die das zu Hause im Sinne einer Klassenarbeitsvorbere-
211 itung und wir schauen später noch einmal darauf.
212 **Interviewer:** Damit Schüler vielleicht auch gezielter noch einmal Fragen stellen könnten.
213 Ja, auf jeden Fall. Ich finde, das muss auch nicht nur im Unterricht angeleitet sein. Also
214 am Anfang sicher bis sie drin sind, aber ab Klasse acht kann man das auch nach zwei oder
215 drei Durchführungen alleine machen lassen.
216 **Interviewer:** Dann schon die letzte Frage. Welche weiteren Funktionen würden Sie sich
217 wünschen?
218 **Lehrkraft:** Also verschiedene Pfeile, um die Komplexität von Wissen, Beziehungen, Auswirkun-

219 gen, wechselseitigen Beeinflussungen variabler darstellen zu können. Dann außerdem an-
220 dere Formen. Vielleicht auch einen Fundus, den die Lehrkraft freischalten kann, in gewis-
221 sem Umfang. Da andere Formen, aber auch andere Farben. Und die Möglichkeit vielleicht
222 Begriffe in einen Container zu setzen und dem Schüler zu sagen: Entweder hast du da
223 noch welche zur Auswahl, falls du die brauchst oder er bekommt noch drei oder vier leere
224 Container, wo er einfach noch ein Begriff setzen kann. Diese Option wäre sicher für einen
225 Schüler spannend. Vor allem unter dem Aspekt der Differenzierung. Die Variante, dass ein
226 Schüler sich die Maps selbst anschauen kann. Wenn er jetzt das Gefühl hat, jetzt habe ich
227 das Thema verstanden. Jetzt habe ich eigentlich die für mich nachvollziebarste Concept
228 map erstellt, die speichere ich mir ab und die kann ich mir ausdrücken oder mal angucken.
229 Die habe ich dann schon einmal so eine Abcheckliste. Begriffen habe ich halt das visuelle
230 Bild, wenn ich mich auf irgendetwas vorbereite. Das hilft sicher, um mich selber über-
231 prüfen zu können. Auch zu sehen: Hey, das habe ich einmal gewusst. Mit dem Begriff
232 konnte ich einmal etwas anfangen. Das wäre sicher auch schön. Der Verlauf kann auch
233 aufschlussreich sein. Er kann motivieren, aber auch Aufschluss geben, was ich vergessen
234 habe. Es zeigt den Schülern auch, dass Lernen ein Prozess ist. Auch das funktioniert
235 in Wiederholungsschleifen. Ich hatte das Wissen in der Einheit vielleicht mal parat und
236 wusste es aus dem Unterrichtsgeschehen, aber wenn ich es in sechs Wochen noch ein mal
237 brauche, merke ich, dass ich noch einmal rann muss, damit ich eben diese Verknüpfungen
238 wieder alle parat habe. Gleichzeitig sehe ich aber auch, ich hatte sie ja schon einmal da und
239 muss vielleicht nur den Staub abkehren und es hervorholen. Das kann auch motivierender
240 sein als das Gefühl zu haben ich lese den Text zum fünften Mal und blicke es immer noch
241 nicht.
242 **Interviewer:** Könnten sie sich vorstellen, dass für die Auswertung so Durchschnittssachen
243 nützlich wären? Wir hatten vor dem Gespräch kurz über midi maps gesprochen.
244 **Lehrkraft:** Ich persönlich halte von Durchschnittswerten nichts. Wie bei einer Klasse-
245 narbeit sagt der Durchschnitt nicht viel aus. Für mich ist es oftmals eher spannend zu
246 sehen, konnten manche mit allem etwas anfangen, haben andere vielleicht auch einfach
247 komplett versagt. Also bei einer concept map ist es ja schwierig und repräsentiert das
248 eigene Denken, also glaube ich nicht, dass es die Ideale Lösung gibt. Es gibt vielleicht
249 Ideen, die näher an das kommen, um die Komplexität abzubilden. Wenn die Schüler das
250 hätten und sehen würden, wie ist denn jetzt meine Concept map im Verhältnis zu der von
251 jemand anderem. Aus dem und dem Gespräch darüber kann der Schüler mehr mitnehmen.
252 Das Wissen zu einzelnen finde ich interessanter.
253 **Interviewer:** Wir hatten vorher auch kurz über das Konzept von Scoring gesprochen. Wie
254 stehen Sie dem gegenüber?
255 **Lehrkraft:** Dem stehe ich ganz ähnlich gegenüber. Es ist einfach nicht möglich, den
256 Fortschritt einer Klasse in einer Zahl abzubilden. Ich glaube, ein wichtiger Teil der Infor-
257 mationen geht verloren, denn man sieht ja nicht, was fehlt. Ich denke, man muss sich die
258 Ergebnisse schon anschauen.
259 **Interviewer:** Vielen Dank für dieses Interview.
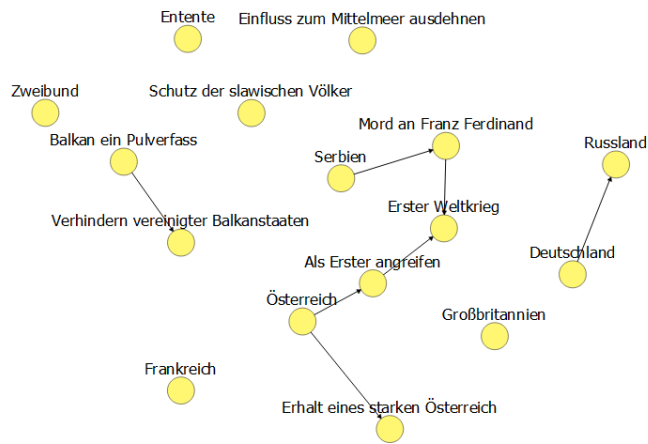
8.3 Layout example

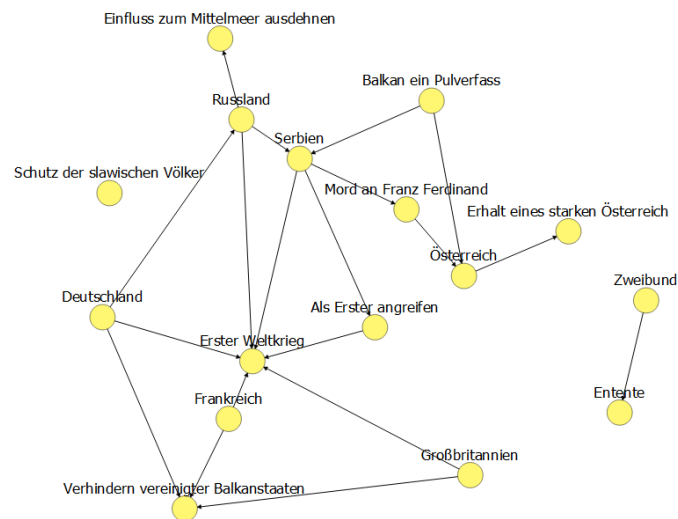## 8.3.1 Without layout

Figure 24 The original files at t = 0

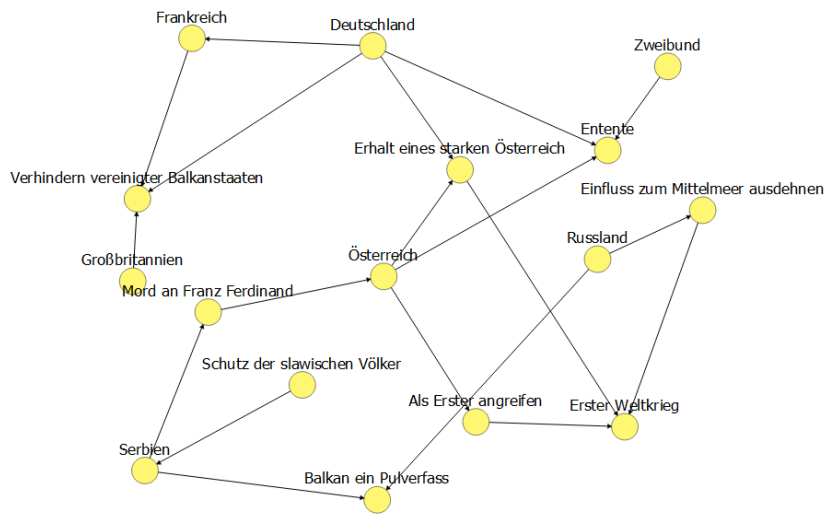**Figure 25** The original files at t = 1

Figure 26 The original files at t = 2
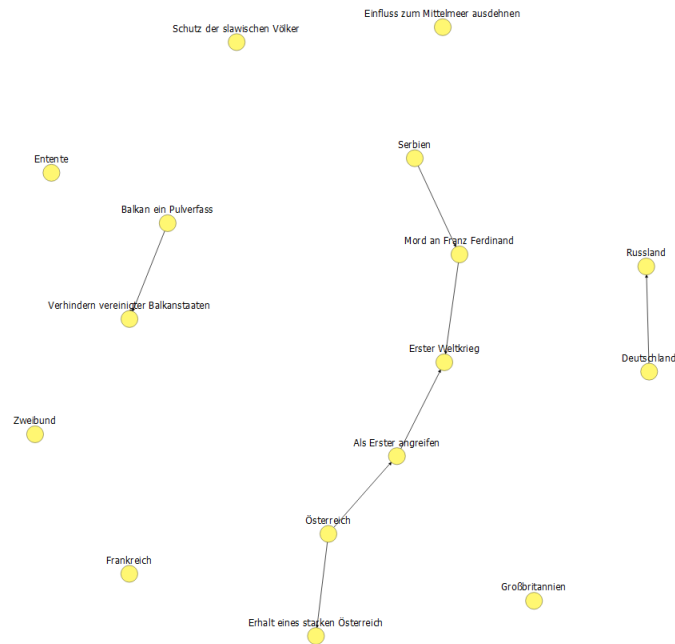
8.3.2 With individual quality 100%

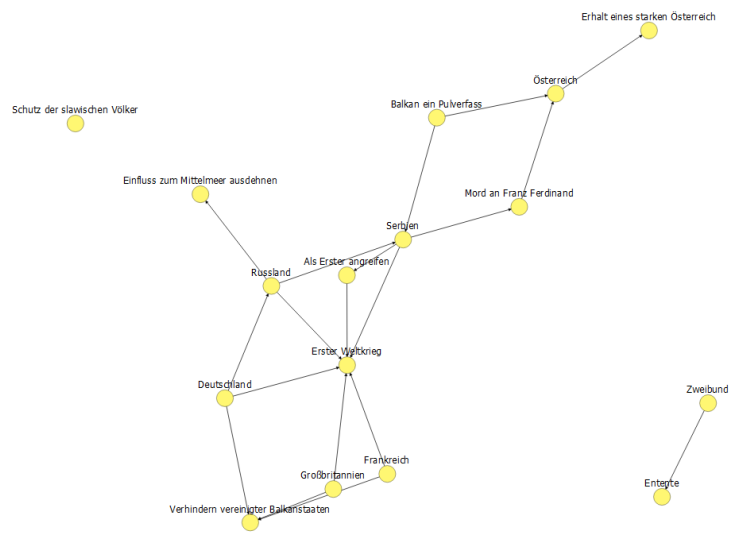**Figure 27** With individuell quality 100% at t = 0
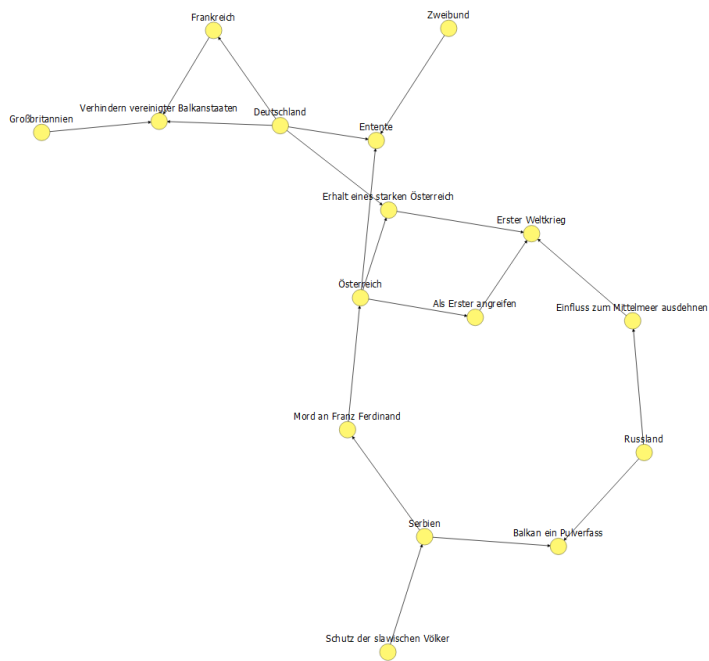
Figure 28 With individuell quality 100% at t = 1

Figure 29 With individuell quality 100% at t = 2

8.3.3 With individuell quality 80% and stability 20%

Figure 30 With individual quality 80% and stability 20% at t = 0
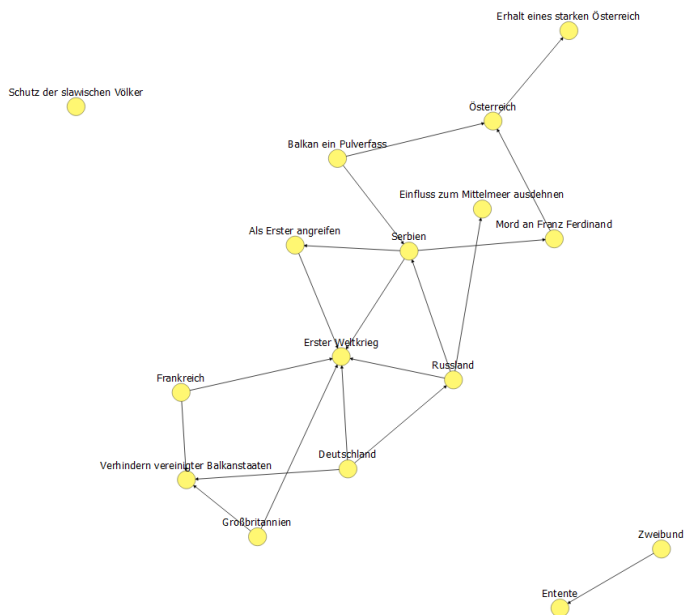
Figure 31 With individual quality 80% and stability 20% at t = 1
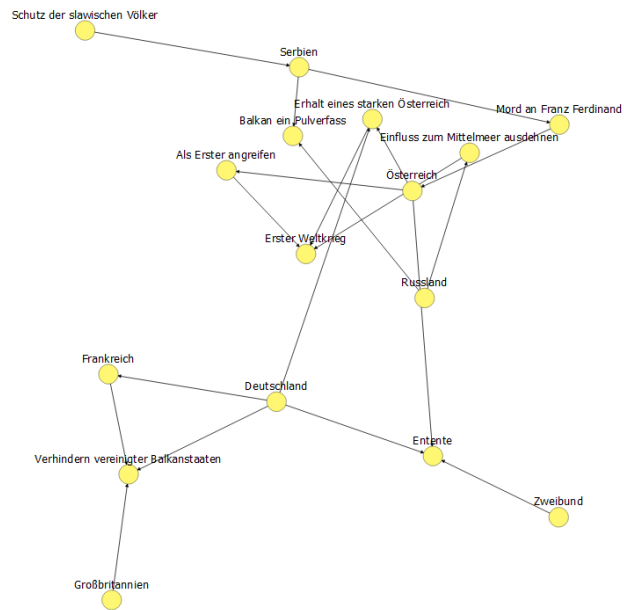
Figure 32 With individual quality 80% and stability 20% at t = 2

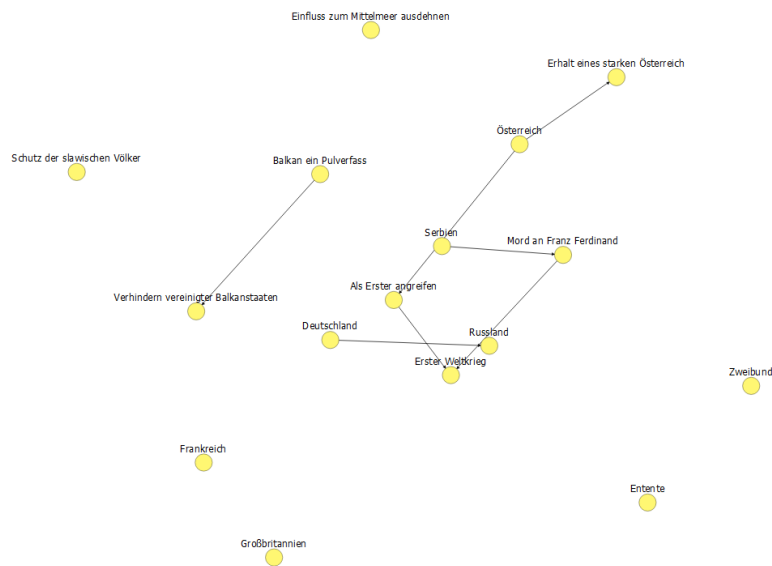## 8.3.4 With individual quality 50% and stability 50%

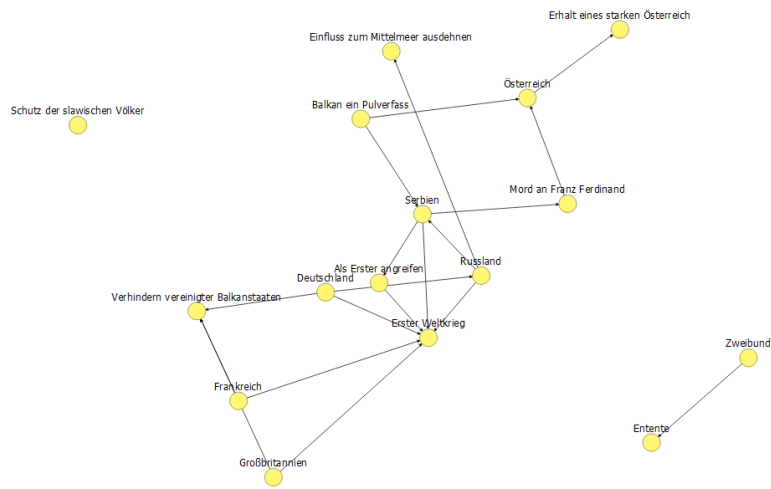**Figure 33** With individual quality 50% and stability 50% at t = 0

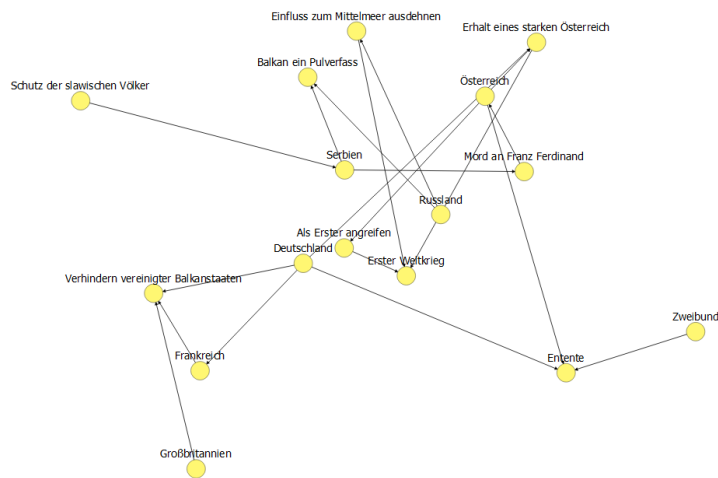**Figure 34** With individual quality 50% and stability 50% at t = 1
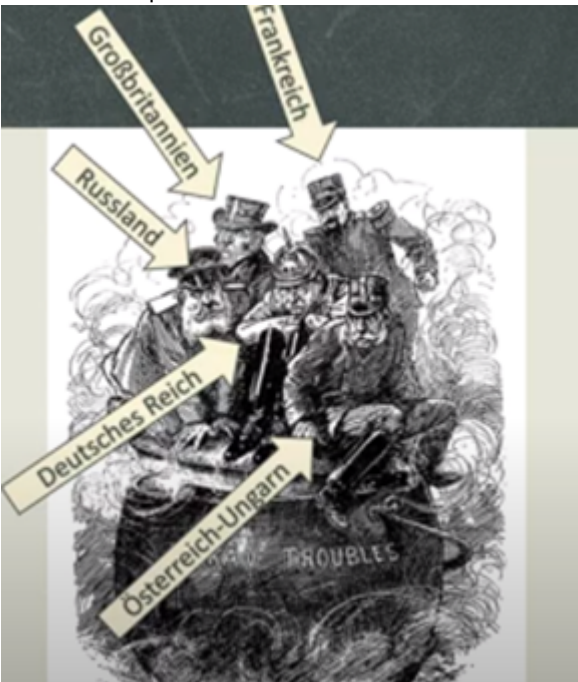

Figure 35 With individual quality 50% and stability 50% at t = 2

8.4 Lesson plans

8.4.1 Der Balkan, ein Pulverfass

Fach: Geschichte
Klasse: 8
Thema: Der Balkan, ein Pulverfass.
Datum: 08.06.2023
Buch: Geschichte und Geschehen. Schülerband 8. Klasse.

Zeit	Phase	Unterrichtsverlauf	SF	Material
10 min	Einstieg	Karikatur LE Petit Journal: - Beschreiben, - Analysieren, - Interpretieren. Annexion Bosniens durch Österreich-Ungarn und Unabhängigkeitserklärung Bulgariens. Karikatur der französischen. Zeitschrift Le Petit	UG	PPP
15	EA1	Verlauf: Buch S. 134 A. 1: Seid bereit eure Ergebnisse zu präsentieren. - Österreich-Ungarn schluckt Bosnien und Herzegowina 1908, - Serbien Vergrößerung 1913, - Vergrößerung Bulgarien 1913, - Zurückdrängung Osmanisches Reich 1913, - Albanien entsteht 1912/13.	PA	Buch

10 min	Sicherung	2 Schülerpräsentationen	SP	ELMO
10 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads
5 min	Pause	-	-	-
5 min	EA2	Der kochende Kessel: Buch S. 134 Q1 - Beschreiben, - Analysieren, - Interpretieren. 	UG	Buch

15 min	EA3	Buch S. 135 A. 2: Nicht als Bericht, sondern stichpunktartig.
		- Russland Einfluss zum Mittelmeer hin,
		- Großserbische Bewegung als Gefahr für Vielvölkerstaat Ö-U,
		- Russland steht hinter Serbien:
		  - **Hinweis: Panslavismus**
		  - Ziel war die kulturelle, religiöse und politische Einheit aller slawischen Völker in Europa.
		- Potenzial Weltenbrand,
		- Vermittlung eines Friedensvertrags durch Großmächte 1913.
			-
			EA
				Buch

15 min	Sicherung	Sammlung an der Tafel	UG	Tafel
10 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads

8.4.2 Ein Weltenbrand entsteht.
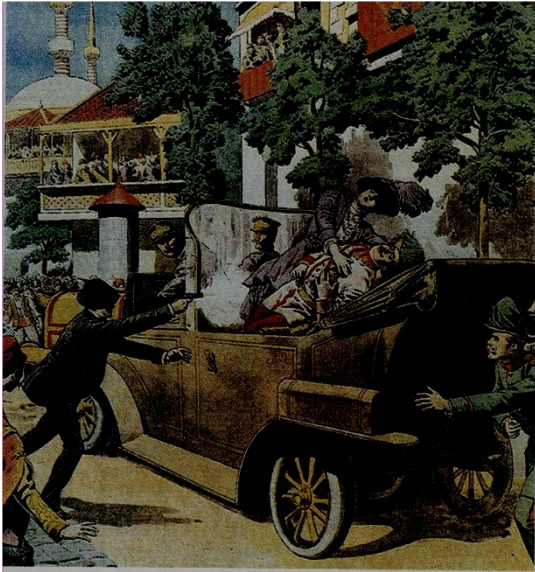
Fach: Geschichte
Klasse: 8
Thema: Ein Weltenbrand entsteht.
Datum: 14.06.2023
Buch: Geschichte und Geschehen. Schülerband 8. Klasse.

Zeit	Phase	Unterrichtsverlauf	SF	Material
10 min	Einstieg	Buch S. 136 Q1 - Beschreiben, - Analysieren, - Interpretieren 	UG	PPP
15 min	EA1	Historische Ereignisse - Buch S. 137 A.2 stichpunktartig: - Mord an Franz Ferdinand, - Deutschland sagt Unterstützung zu, - Wien gibt Liste mit Forderungen an Serbien, - Serbien ist bereit alle zu erfüllen außer von Österreichern geführte Ermittlungen in Serbien, - Österreich erklärt Serbien den Krieg, - Deutschland und Russland mobilisieren Armeen, - Einmarsch in Belgien führt zu britischer Kriegserklärung.	EA	Buch

10 min	Sicherung	An der Tafel als Flussdiagramm.	UG	Tafel
5 min	-	Einführung Concept maps	LV	PPP
5 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads
5 min	Pause	-	-	-

15 min	EA2	Ziele der Parteien - Buch S. 137 A. 3:
		- Österreich:
		   - Verhinderung des Zusammenschlusses der Balkanstaaten.
		   - Gegnern zuvorkommen.
		- Deutschland:
		   - Erhaltung eines starken Österreich ist wichtig.
		   - Konflikt lokalisieren.
		   - Russlands erstarken zuvorkommen.
		- Russland:
		   - Schutz der slawischen Völker. (Panslavismus)
		   - Einfluss zum Mittelmeer ausdehnen (Aus voriger Stunde)
		Hinweis: Zweibund, Entente
			PA	Buch

10 min	Sicherung	Tabelle an der Tafel	UG	Tafel
5 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads
10 min	Diskussion	Offene Diskussion über das Tool.	UA	-

8.4.3 Die Gesellschaft verändert sich.

Fach: Geschichte
Klasse: 9
Thema: Die Gesellschaft verändert sich.
Datum: 20.06.2023
Buch: Geschichte und Geschehen. Schülerband 9. Klasse.

Zeit	Phase	Unterrichtsverlauf	SF	Material
10 min	Einstieg	Buch S. 136 Q1 - Beschreiben, - Analysieren, - Interpretieren 	SF	Material
20 min	EA1	Buch S.176 und 177 lesen : Veränderung der Gesellschaft	EA	Buch
10 min	Sicherung	2 Schülervorträge	SV	ELMO
5 min	-	Einführung Concept maps	LV	PPP
10 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads
5	Pause	-	-	-
20 min	EA2	Buch S. 178 A. 2/3: Die Klasse wird aufgeteilt und jede Hälfte bekommt eine andere Aufgabe.	EA	Buch
15 min	Sicherung	Sammlungen der Ergebnisse an der Tafel.	UG	Tafel
10 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads

8.4.4 Die R.A.F.

Fach: Geschichte
Klasse: 9
Thema: Die R.A.F.
Datum: 27.06.2023
Buch: Geschichte und Geschehen. Schülerband 9. Klasse.

Zeit	Phase	Unterrichtsverlauf	SF	Material
5 min	Einstieg	Schlagzeile Bild: "Die Klimakleber sind die neue R.A.F." Weiß einer, was die R.A.F. ist? Was sagt ihr zu dieser Schlagzeile?	UG	PPP

15 min	EA1	Buch s. 181 Text lesen und folgende Fragen beantworten:
		 - Woraus entwickelt sich die R.A.F.?
		   - Studentenbewegung.
		 - Was sind die Ziele der R.A.F.?
		   - Teil einer internationalen revolutionären Bewegung.
		   - Schaffung einer kommunistischen Gesellschaft.
		   - Freipressen von Kampfgefährten.
		 - Was sind die Methoden der R.A.F.?
		   - Brand in Kaufhäusern,
		   - Bombenattentate,
		   - Morde,
		   - Entführung.
			PA	Buch

10 min	Sicherung	Sicherung an der Tafel	UG	Tafel
10 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads
15 min	EA2	spezifisches Beispiel: Buch S. 183 A. 2 und 3: Aushebeln des Rechtsstaates und damit zeigen, dass das System kaputt ist.	SF	Material
10 min	Sicherung	Schülervortrag	SV	ELMO
5 min	Tracking	Durchführung des Trackings mit dem Tool.	EA	IPads
15 min	Diskussion	Offene Diskussion über das Tool.	UA	-