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FROM TOOL TO EXPERIENCE: ESTABLISHING A USER EXPERIENCE PERSPECTIVE ON DIGITAL CONCEPT MAPPING

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From Tool to Experience:

Establishing a User Experience Perspective on Digital Concept Mapping

Björn Rohles

Abstract

Education today faces difficult challenges, particularly because the complexity of topics or problems is rising and requires that learners see connections across different domain boundaries. Consequently, learners and instructors need a systematic approach to build and assess structural knowledge, supporting them to work with complexity in the 21st century. Digital concept mapping is a promising method to address these challenges. Concept maps are graphical networks of concepts and links with a particular emphasis on explicit semantic relations. Digitalization of concept mapping offers a range of capabilities but also adds challenges of its own. As learners take on a simultaneous role of users, the question of how to purposefully design positive experiences in digital concept mapping becomes a key concern. A digital tool needs to be optimized to allow learners to focus on task-relevant aspects instead of investing cognitive resources into operating the tool. Furthermore, a digital tool can itself be a source of positive experiences, contributing to motivation and reaching the overall educational goals. With an insufficient focus on users, designers and researchers risk creating tools that do not adequately acknowledge the aforementioned impacts on education.

The present dissertation argues that the notion of user experience (UX) is adequate for investigating and purposefully shaping learner experiences with concept maps. The dissertation addresses the following research question: How does a user experience-driven approach contribute to digital concept mapping? After a general introduction (Part I), the dissertation builds on eight studies in four main parts: defining objectives of user experience design for digital concept mapping (Part II), investigating user experience design for a digital concept mapping tool (Part III), identifying scoring approaches for concept map-based assessment (Part IV), and investigating the impact of user experience on digital concept mapping (Part V). It concludes with a general discussion (Part VI).

Part II presents three studies. Chapter 2 describes a co-design study in four classes. It combined functionality-driven and experience-driven design and identified a requirements profile for a digital concept mapping tool. Chapter 3 describes a storytelling focus group study that identified the role, desired outcomes, and pain points of digital concept mapping in Luxembourgish secondary education. Chapter 4 describes an interview study that identified how digital concept mapping contributes to fulfilling psychological needs.

Part III describes the user experience design of a digital concept mapping tool. Chapters 6, 7, 8, and 9 investigate and optimize user experience with a concept mapping tool, building on a combination of critical incidents, think-aloud, card-driven investigation of psychological needs, and interviews. In summary, these studies were able to optimize user experience in digital concept mapping.

Part IV addresses the scoring of concept maps which was identified as a key challenge for instructors and researchers in Part II. Chapter 10 is a systematic literature review of criteria used to score concept maps, resulting in a comprehensive framework with three dimensions that define concept map scoring.

Finally, Part V presents two studies measuring the impact of a user experience perspective on digital concept mapping. Chapter 11 investigates user experience, psychological needs, intention to use, and concept map scores. Psychological needs strongly determined positive user experience, but not universally across all needs. User experience strongly impacted intention to use. Furthermore, our results indicated the need for further research into the relation between user experience and scores. Chapter 12 presents work in progress on guidelines and a scoring rubric for the meaningful use of multimodal features (like color, shape, or line type) in digital concept mapping.

The present dissertation contributes empirical results to establishing a user experience perspective by identifying functional and non-functional goals, contextual factors, desired outcomes, pain points, and functionalities and characteristics of digital concept mapping tools. Furthermore, it outlines how these requirements can be achieved with UX design. The dissertation also contributes theoretical and meta-analytical findings by proposing a profile of psychological needs for concept mapping and deriving a comprehensive framework of criteria used to score concept maps. Finally, the dissertation makes methodological contributions by demonstrating how humans can be systematically involved in shaping their experiences with digital concept maps. The dissertation also provides recommendations for future design and instruction.

List of Journal Publications

Chapter	Related Publication	Status
Chapter 2	Rohles, B., Koenig, V., Fischbach, A., & Amadieu, F. (2019). Experience matters: Bridging the gap between experience- and functionality-driven design in technology-enhanced learning. Interaction Design and Architecture(s) Journal - IxD&A, 42, 11-28.	Published in IxD&A
Chapter 10	Rohles, B., Fischbach, A., Amadieu, F., Koenig, V. (in preparation). Scoring Concept Maps: From a Systematic Review Towards a Comprehensive Framework.	in preparation for journal publication (in revised form)
Chapter 11	Rohles, B., Backes, S., Fischbach, A., Amadieu, F., Koenig, V. (submitted). Creating Positive Learning Experiences With Technology: A Field Study on the Effects of User Experience for Digital Concept Mapping.	submitted for journal publication
Chapter 12	Rohles, B., Fischbach, A., Amadieu, F., Koenig, V. (in preparation). “Each Shape Has a Meaning”: Towards a Multimodal Grammar for Concept Maps.	in preparation for submission

Despite the cumulative nature of this dissertation, four studies are included that are currently not in the process of publication. I am planning to submit publications based on these studies in the future. In addition to the included studies, the following conference publications are related to this dissertation:

- Rohles, B., Fischbach, A., Amadieu, F., Koenig, V. (2021, July 9-12). Knowledge assessment with concept maps: Opportunities and challenges. In ITC Colloqium 2021, online.
- Backes, S., Rohles, B. (2021, September 6-10). Learning about Soil and Sustainability with a Concept Mapping Tool: How Does Concept Mapping Help to Represent Complex Knowledge? In ECER 2021, online.
- Rohles, B., Backes, S. (2021). Wissen zu Nachhaltigkeit und Verständnis für komplexe Zusammenhänge – eine Concept-Mapping-Studie. In: Nationaler Bildungsbericht 2021.

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PART I:

General introduction

1 Introduction

1.1 Digital Concept Mapping and the Challenges of 21st-Century Education

> Working life will change in the next ten years. It is likely that we will need more creative humans, that we will need more positions involving leadership, humans with ideas, humans with the skills to self-organize. […] Furthermore, speaking of the 21st-century skills that children need to have – collaboration, talking and discussing with others, critical thinking… All of that fits perfectly. All of these 21st-century skills are covered, and this is yet another tool that children use to enter into working life later.

The above quote by an instructor (see Chapter 4) summarizes many of the challenges facing education today. The amount of information and knowledge is rapidly growing in many domains (Keller & Tergan, 2005). Learners must increasingly engage in interdisciplinary thinking (Mansilla & Duraising, 2007) and future-oriented systems thinking to address contemporary problems (Vester, 2001). Large-scale societal trends like multilingualism and increasing diversity demand new approaches for addressing them. Humans need to engage in meaningful exchange that allows to understand the perspective of others for solving today's complex problems, where no single person can see all that is required to address them (Basque & Lavoie, 2006; Newell & Proust, 2018). Because of these developments, complexity is rising rapidly, which education needs to prepare learners to deal with. Thus, new competencies are becoming key objectives in education, such as structural knowledge, meta-cognition, self-regulated learning, digital skills, problem-solving, or critical thinking (so-called "21st-century skills"; Binkley et al., 2012; Mayrath et al., 2012; Nicol & Macfarlane-Dick, 2006; Redecker & Johannessen, 2013; van Laar et al., 2017). These competencies should prepare learners to meet future challenges in society and in their careers.

Concept mapping is a promising approach for building these competencies: As a knowledge visualization method with node-link diagrams, it allows learners to actively connect new to existing knowledge (Novak & Gowin, 1984), focus on structures of knowledge (Jonassen & Marra, 1994), and engage in 21st-century skills like systems thinking (Brandstädter et al., 2012), critical thinking (Wei & Yue, 2016; West et al., 2000), problem-solving (Barroso & Crespillo, 2008; Hwang et al., 2014; Layne et al., 2010; Lee & Nelson, 2005; Okebukola, 1992; Stoyanova & Kommers, 2002), and meta-cognition (Novak & Gowin, 1984). Concept mapping is a language-reduced methodology that emphasizes structural relations (Nesbit & Adesope, 2013) and allows learners to understand and integrate others' perspectives (Newell & Proust, 2018). The digital transformation has increased concept mapping capacity (Alpert & Grueneberg, 2000; Anderson-Inman et al., 1998; Bruillard & Baron, 2000; Hwang et al., 2012), but – as the following section will show – is itself a fundamental challenge that the present dissertation will address.

1.2 The Need to Include User Experience as a new Perspective in Digital Concept Mapping

In addition to the outlined challenges and the potential of concept mapping to address them, there is a second major trend at the core of the present dissertation: the increasing digitalization of education[1]. This involves more than transferring traditional approaches to new digital media, it involves fundamental changes in learning and assessment (Ng, 2015; Redecker & Johannessen, 2013). Digital technology offers new capabilities, such as easy-to-use interfaces that encourage the active restructuring of concepts (Anderson-Inman et al., 1998; Bruillard & Baron, 2000; Hwang et al., 2012), meaningful multimodal visual elements (Alpert & Grueneberg, 2000; Tien et al., 2018), hyperlinks to related content (Amadieu & Salmerón, 2014; Wang et al., 2019b), and opportunities to record the process of creating concept maps (Miller et al., 2008).

However, these advantages of digital technology in education do not come automatically, but need to be carefully designed. The need to carefully design technology has long been highlighted in the discipline of human-computer interaction (HCI). HCI is defined as "a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (Hewett et al., 1992, p. 5), and is situated at the intersection of humanity and technology. In the last two decades, the concept of user experience (UX) has emerged as a key perspective for investigating how humans interact with technology within the field of HCI (Bødker, 2006; Harrison et al., 2007; Lallemand & Koenig, 2017). UX captures what users perceive and experience regarding a system, product or service (International Organization for Standardization [ISO], 2018) and aligns well with the shift to "learner-centered education" (Norman & Spohrer, 1996; Reigeluth et al., 2017). However, while UX is well-established in industry, research on educational technology (and concept mapping in particular) rarely takes a user experience perspective (Weinerth et al., 2014a). This lack of focus on user experience can create numerous problems. Unoptimized tool design can prevent learners from successfully completing learning and assessment tasks (International Test Commission [ITC], 2006; Tselios et al., 2001). Consequently, non-task-related competencies like information and communication technology (ICT) literacy (Katz & Macklin, 2013; Siddiq et al., 2017) impact learners' performance. In addition, not adequately considering users' perspectives when designing educational technology can reduce designers' ability to create positive, engaging learning experiences (Hassenzahl, 2010) – experiences that motivate learners to concentrate on the task and ultimately reach their educational goals. Finally, digital education tools might not meet users' expectations when users are not adequately involved in the creation of educational technology (Druin, 2002). Consequently, they might not adopt a specific educational technology (Alexandre et al.,

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[1] In the present dissertation, I adopt the term "digitalization" to refer to deep transformation processes (including the creation of new values or capabilities) due to digital technologies, as compared to the term "digitization," which refers to the process of converting analog into digital data (Brennen & Kreiss, 2014; Orellana, 2017; Gobble, 2018).

2018). Thus, as the field of education becomes increasingly digitalized, the topic of user experience has become timelier and increasingly impacts learning and assessment.

The present dissertation systematically addresses this research gap and investigates the role of user experience (UX) in digital concept mapping. It addresses the following overarching research question:

How can a user experience-driven approach contribute to digital concept mapping?

Why would digital concept mapping benefit from an investigation of UX? UX is a holistic concept that examines humans' experiences with technology (Bargas-Avila & Hornbæk, 2011). From a UX perspective, two dimensions fundamentally impact how humans experience technology: the pragmatic and hedonic dimensions. Both address different reasons how digital concept mapping could benefit from an investigation of UX:

- First, when digital technology is used for concept mapping, learners and instructors simultaneously take on the role of *users* (Ramiel, 2019). Consequently, they need to understand and operate the technology in order to support their instrumental goals. An appropriate, highly usable digital concept mapping tool is needed to ensure that users are able to reach their goals. These reflections are coved by the pragmatic dimension of UX, particularly the concept known as "usability", but studies on its impact on digital concept mapping are rare (Weinerth et al., 2014a). Nevertheless, research suggests that usability affects scores obtained with digital concept mapping tools (Weinerth, 2015). These findings suggest that considering the pragmatic dimension of UX in digital concept mapping is vital in order to ensure optimal conditions for learning and assessment with digital concept maps.
- Second, digital technology is more than just a "means to an end" for achieving an instrumental goal like completing a test. As education becomes increasingly digitalized, technology is affecting many other types of experiences, including cognitive, motivational, emotional, and other psychological processes (Hassenzahl, 2010). The hedonic dimension of UX covers these processes (Diefenbach et al., 2014a; Hassenzahl & Tractinsky, 2006), but the role of the hedonic dimension of user experience in digital concept mapping has not yet been explored. However, this perspective is vital to ensure that digital concept mapping creates positive experiences, which have been found to impact learning and assessment in education (Alexander et al., 2014; Edelmann, 2000; Levesque et al., 2004). Furthermore, education is about more than instrumental, measurable learning outcomes (e.g., grades) but serves multiple broader purposes, including qualification, socialisation, and subjectification (Biesta, 2009). The hedonic dimension helps to acknowledge these broader purposes in the design of educational technology.

In this introduction, I[2] will first present the state-of-the-art in current research, focusing on (a) why I think concept mapping is a promising approach to address the challenges outlined above, and (b) why I think user experience is a key concern with respect to digital concept mapping. Both sections will answer three key questions: the "what" ("what is concept mapping?" and "what is user experience?", respectively), the "why" ("why is concept mapping important?" and "why is user experience important?", respectively), and the "how" ("how are concept maps used?" and "how can a positive user experience be achieved?", respectively).

The main part of the dissertation is organized into four parts with eight studies. Three studies in Part II establish objectives for user experience in digital concept mapping. They include a co-design study (Chapter 2), a storytelling study (Chapter 3), and an interview study examining psychological needs in digital concept mapping (Chapter 4). Part II wraps up with a synthesis of the findings and a prioritization of requirements for the to-be-designed digital concept mapping tool (Chapter 5). Part III builds on prior work by Katja Weinerth (2015) and Eric François (described in Chapter 6) and investigates how a concept mapping tool's design affects user experience in several design iterations (Chapters 7, 8, and 9). Part IV addresses scoring concept maps by conducting a systematic literature review study (Chapter 10). Scoring concept maps was one of the key challenges for instructors and researchers identified in my studies. The findings of Chapter 10 are synthesized into a comprehensive framework as well as a set of guidelines. Part V investigates the impact of user experience on digital concept mapping by measuring its relations to psychological need fulfillment, intention to use, and concept map scores (Chapter 11). Furthermore, it presents a work-in-progress study on multimodal features in concept maps, which were frequently suggested in the studies making up the present dissertation (Chapter 12). This study identifies use patterns for these multimodal features and suggests materials (guidelines and a scoring rubric) to integrate them into concept mapping. Finally, Part VI presents a general discussion of the various findings in the present dissertation (Chapter 13).

This dissertation makes several contributions that I will now outline briefly, building on suggestions by Wobbrock and Kientz (2016).

- Empirical contributions include insights into what defines user experience in digital concept mapping (i.e., functionalities, characteristics, contextual factors, and underlying reasons), iterative enhancements to the design of a digital concept mapping tool, and validation of the impact of user experience by researching its relation to several other variables, specifically fulfilment of psychological needs, intention to use, and concept mapping scores.
- Theoretical and meta-analytical contributions include a profile of psychological needs in digital concept mapping and a comprehensive framework for scoring concept maps.

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[2] In the present dissertation, I adopt the recommendations in the Publication Manual of the American Psychological Association regarding the use of personal pronouns. Thus, I will use "I" for individually written chapters, and "we" when an author team was involved in writing a chapter (American Psychological Association, 2020).

- Methodological contributions include co-design and storytelling methodologies that include users in early design stages as well as guidelines and a scoring rubric for applying multimodal (i.e., visual) features in digital concept maps.
- Artifact contributions include recommendations for designing a digital concept mapping tool and materials for instructors on the topics of scoring and the meaningful use of multimodal features.

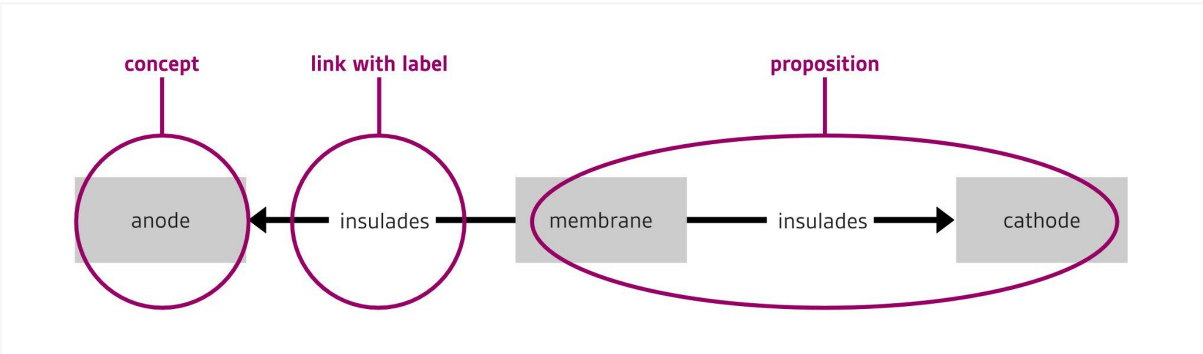
1.3 Current State of Research

1.3.1 Concept Mapping as an Approach to Addressing the Educational Challenge of C21 Skills

1.3.1.1 What Concept Maps are: Definition and Theoretical Foundations

Concept maps (Novak & Gowin, 1984) are graphical representations of knowledge or processes that explicitly depict the relationships between different aspects (Weinerth, 2015). Concept maps have two key components for depicting such relationships (see Fig. 1): concepts and links. A concept is a "perceived regularity in events or objects, or records of events or objects, designated by a label" (Novak, 1990, p. 29), usually depicted inside shapes. A link is a connection between concepts, which can be either directed or undirected. Concept maps typically use labeled links to categorize the semantic relations between related concepts (Shavelson et al., 2005). Semantic units, which encompass both concepts and labeled links, are known as propositions (Ruiz-Primo, 2004).

Fig. 1: *Key components of concept maps*



Concept maps and related methods of knowledge visualization

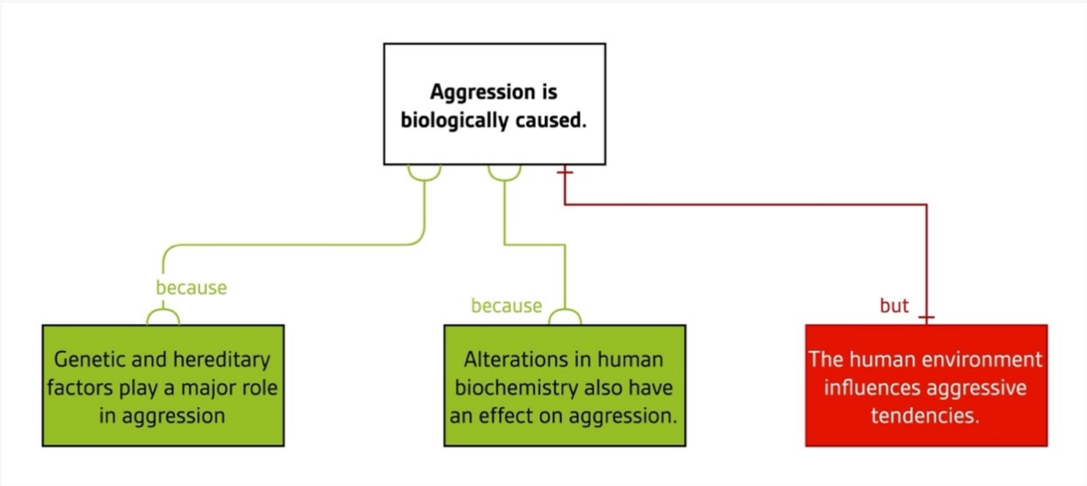
The present dissertation concerns concept mapping in the tradition of Joseph Novak (Novak, 2010; Novak & Gowin, 1984). However, different methodological traditions exist that share the name "concept mapping". In particular, the group concept mapping method (Goldman & Kane, 2014; Kane & Trochim, 2008) asks participants to brainstorm and sort statements regarding a topic of interest based on their similarity. Afterwards, multivariate analyses are conducted to create aggregated clusters of statements. Finally, participants label and interpret the clusters (Goldman & Kane, 2014). Although this tradition of group concept mapping is outside the scope of the present dissertation, researchers have successfully combined the two methods (Wells et al., 2014). Furthermore, various similar methods exist:

- **Cognitive maps**: Concept maps are typically created by learners and include labeled links specifying the exact semantic relations between concepts. Cognitive maps, however, are typically created indirectly (for example, by asking learners to evaluate the degree of similarity between words) and visualize the associations between concepts, without explicitly labeled links (Shavelson et al., 2005).
- **Knowledge maps**: Concept maps typically include links with freely chosen labels (either by the instructor or by the learners). Knowledge maps (Dansereau, 2005) apply a fixed set of pre-defined relations (O'Donnell et al., 2002; Schroeder et al., 2018).
- **Mind maps**: Concept maps emphasize the semantic relations between concepts. Mind maps (Buzan & Buzan, 2010) emphasize the associative connections between ideas (without specifying the semantic relations) and are quite visual in nature (see Fig. 2). Their focus on creativity makes mind maps a good fit for brainstorming but less appropriate for visualizing complex relations (Eppler, 2006; Davies, 2011).

Fig. 2*: Example of a mind map*

- **Argument maps**: Concept maps are typically used to visualize knowledge structures (Shavelson et al., 2005). Argument maps (see Fig. 3) focus on the structure and plausibility of an argument using colors (green for supporting and red for opposing claims) and labelled links like "because" and "but" (Davies, 2011; Dwyer et al., 2013).

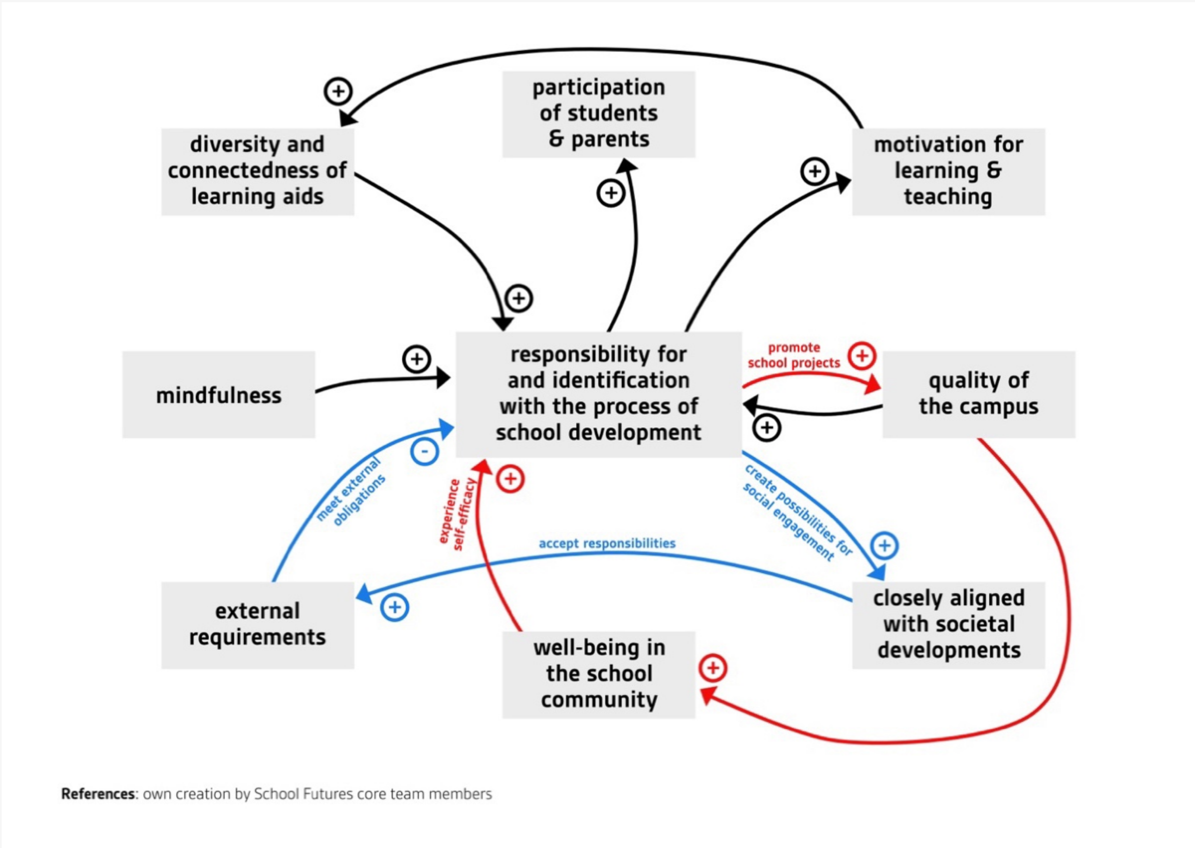
Fig. 3: *Example of an argument map, adapted from Dwyer et al. (2013)*



In addition, there are many more visualization methods that serve specific purposes, such as UML diagrams (Object Management Group, 2017) or flowcharts.

Finally, several variations of concept maps exist. Novak and Gowin (1984) originally suggested a hierarchical structure: Concept maps were supposed to move from general concepts at the top to more specific concepts at the bottom, in line with the assumption that memory is organized hierarchically (Jacobs-Lawson & Hershey, 2002; Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996). However, not all theories of cognition assume that memory is hierarchically structured. For example, associationist theories of cognition argue that memory is organized into networks of associations (Deese, 1965), and concept maps in these traditions have a non-hierarchical network structure (Lopez et al., 2014; Ruiz-Primo & Shavelson, 1996). Furthermore, the focus on semantic relations in concept maps makes representing dynamic relations difficult, which is particularly an issue for research in the tradition of systems thinking (Safayeni et al., 2005). Consequently, researchers have extended concept maps with circular, dynamic links (see Fig. 4) and symbols like "+" and "-" indicating the impact of changes (Palmunen et al., 2013; Safayeni et al., 2005). Concept maps in this tradition are very similar to influence diagrams (Newell & Proust, 2018) and causal loop diagrams (Richardson, 1997).

Fig. 4*: Example of a dynamic concept map on the problem of "How to make learners and instructors feel responsible for the school development process?"*



Theoretical background on concept maps in theories of cognition

Concept mapping is based on a cognitive view of learning (Jonassen et al., 1997; Lopez et al., 2014). Concept maps are based on the theory of meaningful learning (also known as the assimilation theory of learning; Ausubel, 1968). This theory emphasizes that learners actively connect new knowledge to existing knowledge structures (known as the *assimilation* of knowledge; Novak, 2010). Ausubel (1968) suggested that it is this active effort to integrate new knowledge that makes learning *meaningful* (as opposed to *rote learning,* where no such effort is made; Novak, 2010). A detailed discussion on the theories of cognition behind concept maps can be found in Chapter 10, with particular focus on how they affect the scoring of concept maps.

1.3.1.2 Why Concept Maps are Important: Seven Key Advantages

There are three typical use cases for concept maps in education (Nesbit & Adesope, 2013): a) presenting learners with instructional materials in the form of concept maps, b) asking learners to create concept maps as a way to express their knowledge or thinking processes, either individually or collaboratively, and c) using learner-generated concept maps to assess knowledge. There is a wealth of studies on the educational benefits of concept maps (Nesbit & Adesope, 2006; Schroeder et al., 2018). The following section outlines seven key advantages of concept maps (Nesbit & Adesope, 2013).

1 – Integrated visualization of verbal and visual information

The combination of verbal and visual information in concept maps might allow learners to directly process the visually encoded aspects of meaning (e.g., the fact that certain concepts are related) in visual working memory (Nesbit & Adesope, 2013). Presenting information in two modalities can enhance learning if these are meaningfully integrated (Dwyer et al., 2013; Mousavi et al., 1995; Schroeder & Cenkci, 2018), because verbal and visual information are treated as distinct but connected channels in memory (Baddeley, 2000; Mousavi et al., 1995; Nesbit & Adesope, 2006; Paivio, 1990; Schnotz, 2002).

2 – Higher efficiency in representing essential information

Concept maps compress essential information into a concise format that learners can process rapidly (Nesbit & Adesope, 2006). Furthermore, learners decide in which order to read a concept map on their own, allowing for deeper processing of content (Nesbit & Adesope, 2006). Conversely, this need to decide on a reading order can make studying concept maps more challenging than studying texts, especially if visual features and structure are not meaningfully applied to facilitate reading (Blankenship & Dansereau, 2000; Nesbit & Adesope, 2013; see also Chapter 12).

3 – Explicit presentation of important semantic features and complex relationships

Understanding the relations between topics of interest is key to meaningful learning. For complex topics, however, it is difficult to obtain an overview of the semantic relations between different entities. Concept maps make semantic relations more salient than texts by specifying the exact relations between concepts (Schroeder et al., 2018) or collecting all propositions related to a particular concept in a single place (rather than several places within a text; Nesbit & Adesope, 2006; Nesbit & Adesope, 2013). This increased salience of semantics is likely to reduce extraneous cognitive load (Amadieu et al., 2009; Nesbit & Adesope, 2006) and enhance cognitive processing (O'Donnell et al., 2002). Concept maps allow mental tasks to be "off-loaded" from memory to a visual representation, making it easier to deal with complexity (Jonassen et al., 1997).

4 – Enhanced learning effectiveness, particularly in active concept mapping

Concept mapping is generally beneficial for learning across different content domains, especially when learners create concept maps on their own rather than studying concept maps produced by others (Nesbit & Adesope, 2013; Nesbit & Adesope, 2006; Schroeder et al., 2018). Actively identifying the relations among information can enhance comprehension and learning (Amadieu et al., 2015; Freeman et al., 2014; Wittrock, 1990). Furthermore, concept mapping might be particularly beneficial for specific groups of learners. It has an easier grammatical structure than a text and relies less on verbal abilities (Schroeder et al., 2018; Haugwitz et al., 2010; O'Donnell et al., 2002; Nesbit & Adesope, 2013). Thus, concept mapping could be particularly promising in multilingual countries like Luxembourg, where learners from different language backgrounds share the same class. This advantage of concept maps has been found to interact with cognitive ability: Learners with lower cognitive ability particularly profit from concept mapping (Haugwitz et al., 2010).

5 – Developing higher-order thinking skills

Concept mapping is a promising method to help learners build competencies in critical thinking (Wei & Yue, 2016; West et al., 2000), problem-solving (Barroso & Crespillo, 2008; Hwang et al., 2014; Layne et al., 2010; Lee & Nelson, 2005; Okebukola, 1992; Stoyanova & Kommers, 2002) and meta-cognition (Jonassen & Marra, 1994; Novak & Gowin, 1984). These skills number among the so-called higher-order thinking skills (Brookhart, 2010) and are vital for ongoing educational transformations (Ghani et al., 2017).

6 – Potential for collaborative learning

Concept maps are increasingly being created collaboratively (Basque & Lavoie, 2006; Schroeder et al., 2018). They can be easily edited to by all team members (Nesbit & Adesope, 2006; van Boxtel et al., 2002). These qualities of collaborative concept mapping can facilitate exchange in the team (Chen et al., 2018a; Nesbit & Adesope, 2006; Schaal et al., 2010; van Boxtel et al., 2002). Collaborative concept mapping can involve synchronous or asynchronous collaboration (either face-to-face or remotely) with or without a moderator (Khamesan, 2006; Stoyanova & Kommers, 2002). Learners can also be encouraged to discuss individually created concept maps in a peer review (Campbell, 2016; Tifi & Lombardi, 2008).

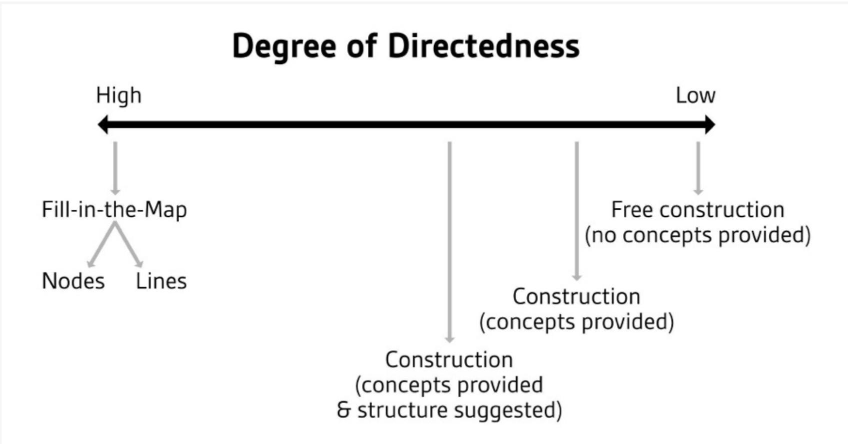
7 – Assessment of complex structural knowledge

Assessment serves multiple purposes (Cizek, 1996; Fischbach, 2012) and is typically differentiated into summative assessment (evaluating learners' achievement by assigning grades; Sadler, 1989; Scriven, 1967) and formative assessment (identifying areas for improvement in order to provide feedback or adapt instruction; Black & Wiliam, 1998; Hattie & Timperley, 2007; Nicol & Macfarlane-Dick, 2006; Redecker & Johannessen, 2013; Sadler, 1989; Scriven, 1967). Concept maps are promising for assessing the structure of knowledge (Novak & Gowin, 1984; Shavelson et al., 2005). This structure is impossible to observe directly, but can be communicated through concept maps (Ifenthaler, 2010b; Jonassen et al., 1997). Concept mapping is also promising if used repeatedly in formative assessment, for example, to identify prior knowledge and then measure learning at various points during instruction (Anohina-Naumeca, 2015; Hay et al., 2008; Trumpower & Sarwar, 2010). At each point, feedback and discussions about the current state of learning and instruction could be integrated (Anohina-Naumeca, 2015). I will discuss concept map-based assessment, particularly its scoring, in greater detail in Chapter 10.

1.3.1.3 How Concept Mapping is Done: Tasks for Learning and Assessment

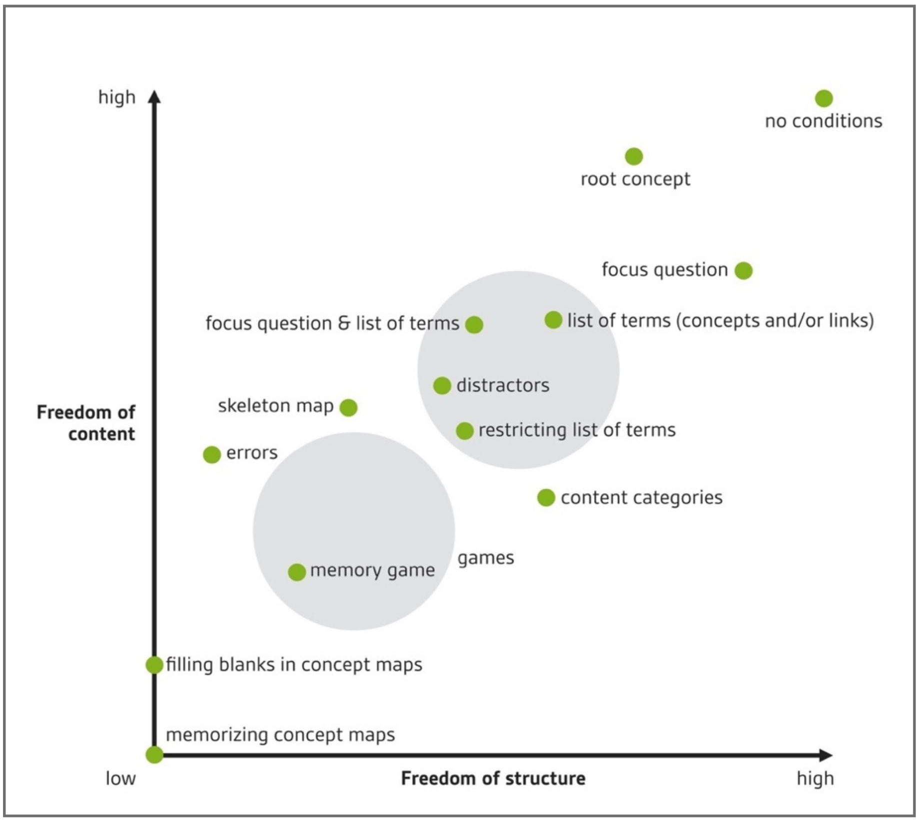
Concept mapping tasks cover a wide spectrum. Ruiz-Primo (2000) distinguished concept mapping tasks based on their degree of directedness (see Fig. 5). Tasks with low directedness give learners maximal freedom in concept mapping. Tasks with high directedness restrict learners' freedom by posing specific requirements. Research indicates that high-directed concept mapping tasks (e.g., providing learners with terms to include in linking phrases) are easier to score than low-directed concept mapping tasks (e.g., allowing learners to select their own terms), but also assess different cognitive processes (Himangshu & Cassata-Widera, 2010; Schau et al., 2001; Yin et al., 2005).

Fig. 5: *Degree of directedness in concept mapping tasks (Ruiz-Primo, 2000)*



Cañas et al. (2012) expanded the degree of directedness into a two-dimensional framework covering freedom of structure and freedom of content. Fig. 6 presents an adapted version of their framework where I added categories, errors, linking terms, and distractors as additional possibilities for concept-mapping-tasks.

Fig. 6: *Taxonomy of concept mapping tasks by Cañas et al. (2012) (adapted)*



At the high end of the freedom continuum, no restrictions are placed on learners. Thus, learners have to define the topic, terms, and structure (Cañas et al., 2012).

In the middle areas of the freedom continuum, learners are typically provided with some elements for their concept maps. These elements might include pre-existing content, focus questions, or lists of terms for concepts and/or links.

First, ***pre-existing content*** refers to providing learners with parts of the concept map to build on. Pre-existing content typically includes the following elements:

- The *root concept* is the central term for the concept map (Cañas et al., 2012). It usually serves as the starting point for progressive differentiation (that is, making concepts increasingly more specific and precise) in concept maps (Novak, 2010) and thus has a strong impact on the content (Cañas et al., 2012). For example, the root concept "digital education" will yield a different concept map than the root concept "opportunities and risks in digital education" because the former is formulated more openly.
- *Skeleton maps* are basic concept maps including the most important concepts, which serve as a starting point for learners. Usually, experts construct these skeleton maps, and learners can build upon and enrich them (Cañas et al., 2012).
- Pre-existing content can include *errors* inside concept maps that learners must identify (Aguiar & Correira, 2014).

- Furthermore, it is possible to distinguish between different content categories in a concept map and provide these categories to learners. For example, Schwendimann (2014) describes concept mapping tasks in genetics where learners are required to position concepts in areas referring to different genotype and phenotype levels.

Second, a ***focus question*** is the central question that a concept map is trying to answer (Cañas & Novak, 2006). Importantly, a focus question impacts both content and structural aspects (Cañas et al., 2012). For example, a focus question like "What does soil do?" is likely to yield concept maps with factual statements about soil. A focus question like "Is soil an existential resource?" is likely to yield concept maps outlining the role of soil in other systems (e.g., the economy, environment, and society). Open-ended focus questions tend to lead to more dynamic propositions (Cañas et al., 2012).

Third, ***lists of terms for concepts and/or links*** specify which terms learners should use in their concept maps. Concept mapping tasks providing such lists of terms in a so-called *parking lot* allow learners to concentrate on creating meaningful propositions (Cañas et al., 2012). Variations exist in terms of whether the provided list is exhaustive (whether learners are permitted to add their own terms) and whether the provided list contains *distractors* (terms that do not relate to the topic; Strautmane, 2012). Furthermore, combinations of these elements are possible, for example providing a root concept and a focus question simultaneously (Cañas et al., 2012).

On the low end of the freedom continuum, a typical concept mapping task would be to provide students with a concept map with blanks to fill in. These blanks can be nodes, links, or both. Learners can be asked to use any terms they find appropriate or to use terms from a provided list (which might include distractors; Strautmane, 2012). However, Cañas et al. (2012) argue that fill-in-the-blank activities encourage rote learning and might misrepresent knowledge.

Other uses of concept maps include games (Kumar et al., 2013) and concept maps as instructional materials to be memorized (Cañas et al., 2012) or advance organizers. An advance organizer precedes explicit instruction (e.g., a text or course unit) and provides a general overview of the upcoming materials. This general overview is intended to activate prior knowledge and help learners meaningfully integrate the subsequent materials (Novak, 2010). Furthermore, concept maps can serve as navigational devices in hypertexts (Amadieu & Salmerón, 2014).

1.3.2 A User Experience Perspective on Digital Concept Mapping

1.3.2.1 Digital Concept Mapping: A Promise…

Although concept maps can be created on paper, digital concept mapping has several advantages. First, digitalization facilitates the concept mapping process, and thus helps learners become aware of their thinking processes and knowledge structures. Concept mapping is an active process of internally negotiating meaning (Jonassen & Marra, 1994). Learners constantly elaborate on the meaning they are communicating and externalize these processes during concept mapping (Jonassen & Marra, 1994).

Digital concept mapping tools have the potential to encourage these processes (Anderson-Inman et al., 1998; Bruillard & Baron, 2000; Hwang et al., 2012), for example by providing easy-to-use interfaces for adding, renaming, or reorganizing elements. Thus, learners might experience stronger feelings of control and involvement in digital concept mapping (Erdogan, 2009). Furthermore, digital concept maps facilitate the integration of visual elements and multimodal documents (Alpert & Grueneberg, 2000; Anderson-Inman et al., 1998; Tien et al., 2018; see Chapter 12). Digital concept mapping tools could make interacting with the digital tool used for digital concept mapping enjoyable, for example, with touchscreen technology on tablets, tabletops, or interactive whiteboards (Baraldi et al., 2006; Hwang et al., 2012).

Second, digitalization offers possibilities specific to the digital medium. For example, digital concept mapping can be enhanced with hyperlinks and hypermedia (Bruillard & Baron, 2000) and aid processing, comprehension and navigation of hypertexts (Amadieu & Salmerón, 2014; Wang et al., 2019b). Furthermore, concept maps can be integrated as graphic organizers into other learning tools (Biswas et al., 2016; Dowell, 2016; Liu et al., 2018; Wang et al., 2019b). Digital concept maps can foster collaborative concept mapping (Draper & Amason, 2014), including remote and asynchronous collaboration, and several methods exist to combine individual concept maps into a joint product, such as mental prints (Giovannella et al., 2007) or modal maps (Eckert, 1998; Fürstenau & Trojahner, 2005).

Third, digital concept mapping has substantial potential to enhance assessment. Typically, such technology-assisted assessment is referred to as “computer-based assessment” (CBA), which aims at “bringing educational measurement and computing resources into relationship with each other” (Bunderson et al., 1988, p. 5). Bunderson et al. (1988) predicted the future development of computer-based assessment in four generations. Their predictions turned out to be remarkably accurate, albeit overly optimistic in terms of timing (Redecker & Johannessen, 2013). First-generation CBA is referred to as *computerized testing* and aims at transferring conventional tests into a digital medium. Second-generation CBA is referred to as *computerized adaptive testing* and involves the adaptation of tests based on learners’ responses, including the degree of difficulty, timing, or content of tasks. Third-generation CBA is referred to as *continuous measurement* and aims to measure performance continuously and unobtrusively, for example using log files. Fourth-generation CBA is referred to as *intelligent measurement* and aims to personalize learning, for example by providing individualized feedback (Bunderson et al., 1988).

The four generations of computer-based assessment are part of a larger shift in education from explicit to embedded testing (Redecker & Johannessen, 2013) and apply remarkably well to digital concept mapping:

- Explicit testing encapsulates first- and second-generation CBA and is concerned with effective and efficient tests (Redecker & Johannessen, 2013). In this regard, Ruiz-Primo and Shavelson (1996) observed a research gap concerning the validity and reliability of concept map-based assessments. Subsequently, validity and reliability have been investigated in studies (McClure et al., 1999; Ruiz-Primo et al., 2001; Shavelson et al., 2005) and meta-reviews (Himangshu &

Cassata-Widera, 2010). In line with this focus on reliability and validity, various methods have been developed to automate the scoring of concept maps (Chang et al., 2005; Chiu & Lin, 2011; Dias et al., 2019; Jain et al., 2014; McGowen & Davis, 2019; Shui-Cheng et al., 2002; Strautmane, 2014). Digital concept mapping makes automated scoring possible for low-directed concept mapping tasks, for example with WordNet (Harrison et al., 2004).

- Embedded testing encapsulates third- and fourth-generation CBA and is concerned with collecting and analyzing data during learning in the form of log data (Hwang et al., 2012; Miller et al., 2008), rather than creating explicit test situations (Redecker & Johannessen, 2013). Log data keeps a "history of everything a student does while using the system" (Mayrath et al., 2012, p. 5). Such log data could be useful for assessing competencies (Mayrath et al., 2012), for example, with a visual interface that allows instructors to play back how students went about constructing their concept maps. In a study of log files created during concept mapping, Miller et al. (2008) found that half of learners' actions related to visual characteristics (e.g., moving objects or changing styling) rather than content- or structure-related characteristics (e.g., adding concepts or modifying text labels). Instructors could use this information to discuss the reasons behind their learners' actions and help them identify areas for improvement. Such feedback could even be automated and in real-time (Redecker & Johannessen, 2013). Feedback could empower learners to uncover their misconceptions and engage in more self-regulated learning (Nicol & Macfarlane-Dick, 2006; Trumpower & Sarwar, 2010). Thus, digital concept mapping tools could facilitate an integrated, learning-centered approach to assessment (Quellmalz & Pellegrino, 2009).

1.3.2.2 … And a Challenge

However, the advantages of digital concept mapping are not a guarantee. Their character as active re-representations of knowledge structures makes concept maps prone to a range of sources of bias (Ifenthaler, 2010b), such as those resulting from differences between concept mapping tasks (Ruiz-Primo & Shavelson, 1996) or individual skills (Erdogan, 2009; Ifenthaler, 2010b). Digital concept mapping adds further dimensions to these potential sources of bias:

- First, the use of digital concept mapping depends on numerous characteristics of individual learners and design. In terms of individual characteristics, competencies like information and communication technology (ICT) literacy (Katz & Macklin, 2013; Siddiq et al., 2017) influence outcomes (Greiff et al., 2014). Some learners have higher competency in learning with digital tools than others. Consequently, numerous authors suggested training on the required tools to bridge these individual differences (Jonassen et al., 1997; Gouli et al., 2003; Weinerth et al., 2014a). Regarding design characteristics, good digital concept mapping tools reduce the impact of non-task-related individual competencies on outcomes. Thus, not only do some learners have higher competency in learning with digital tools, some digital tools have better qualities for learning. If learners do not understand a digital concept mapping tool, their performance might be affected, for example, because they are slower or unable to express the full range of their knowledge (Weinerth, 2015). Such performance issues could lead to improper conclusions in summative or formative assessment. Furthermore, concept mapping is a rather demanding task (Amadieu et al., 2015), meaning that the design of digital concept mapping tools should not add additional demands. These considerations are often discussed in terms of usability but are rarely studied systematically with respect to concept mapping (Weinerth et al., 2014a).

- Second, education is not solely concerned with the transmission of knowledge; thus, digital concept mapping goes beyond finding an effective design for students to create concept maps. In line with educational trends like learner-centered education (Reigeluth et al., 2017) and the shift to embedded assessment (Redecker & Johannessen, 2013), the design of digital concept mapping tools could engage users in meaningful learning, motivate them to actively integrate concept mapping into their learning, and provide a positive environment for their personal growth.

This dissertation investigates how the concept of user experience (UX) aligns with the aforementioned opportunities and challenges in digital concept mapping. In the following sections, I will first discuss what UX is in greater detail, with a particular focus on how user experience relates to the related construct of usability. Second, I will argue why UX is relevant for digital concept mapping. Third, I will outline how a positive UX can be achieved.

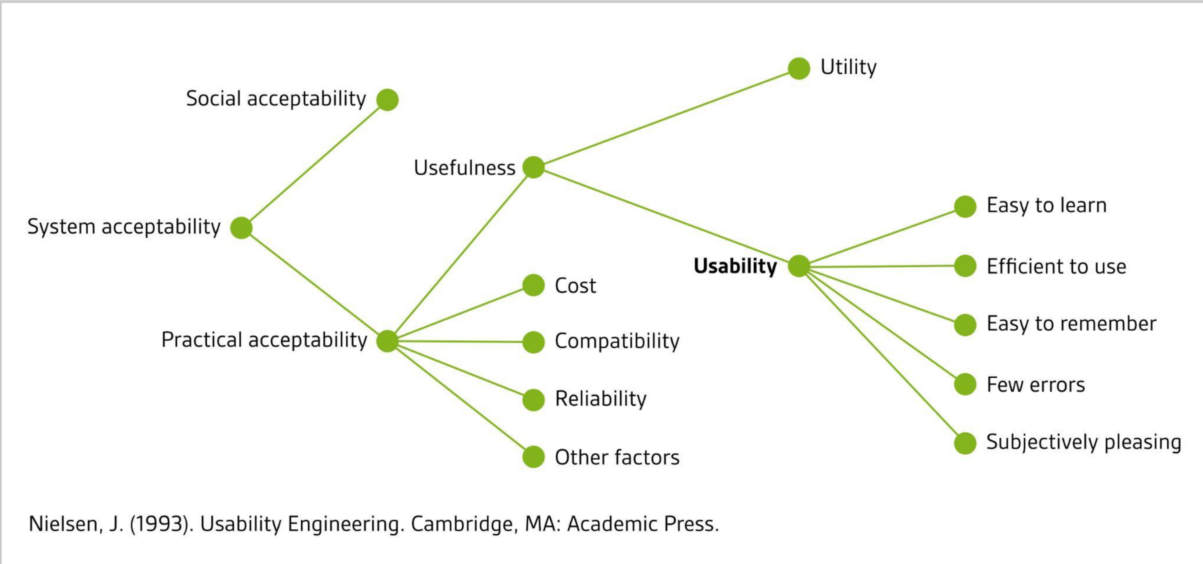
1.3.2.3 What User Experience is: Pragmatic, Hedonic, and Eudaimonic Dimensions of Human Experiences with Technology

In ISO 9241-11, user experience is defined as a "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service" (International Organization for Standardization [ISO], 2018, definition 3.2.3). These perceptions and responses "include the users' emotions, beliefs, preferences, perceptions, comfort, behaviors, and accomplishments that occur before, during and after use" (International Organization for Standardization [ISO], 2018, definition 3.2.3). However, there has been considerable debate about the exact nature of user experience (Lallemand et al., 2015), particularly how it differs from usability.

From usability…

Usability has long been established as a quality criterion of technology (Nielsen, 1993). According to ISO 9241-11, usability addresses the use of a product "by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (International Organization for Standardization [ISO], 2018, definition 3.1). Usability focuses on the design of a product, particularly its user interface (UI) as the "channel for interactions" (Weinerth, 2015, p. 20). Thus, usability does not try to change a person's ability to accomplish a task, but instead optimizes product design to create better conditions for accomplishing a given task (Weinerth, 2015). Usability is one aspect that determines whether users accept a product (Davis et al., 1989; Venkatesh, 2000). Fig. 7 integrates usability with other dimensions affecting the acceptability of a system.

Fig. 7: Usability as it relates to acceptability (Nielsen, 1993)



… to user experience

Building on usability, the field of HCI has increasingly adopted a new, broader perspective in the last two decades. This broader perspective has been labeled the "third wave of HCI" (Bødker, 2006; Bødker, 2015) or "third paradigm of HCI" (Harrison et al., 2007)[3]. It argues that usability alone is insufficient to capture the wide range of human experiences with technology (Hassenzahl, 2003; Krannich et al., 2012; McCarthy & Wright, 2004). Instead, a more comprehensive perspective focusing on the entire user experience is necessary (Lallemand & Koenig, 2017). Thus, UX is understood as a holistic concept (Bargas-Avila & Hornbæk, 2011). It is generally assumed to cover two dimensions: the pragmatic and the hedonic dimension (Hassenzahl, 2001).

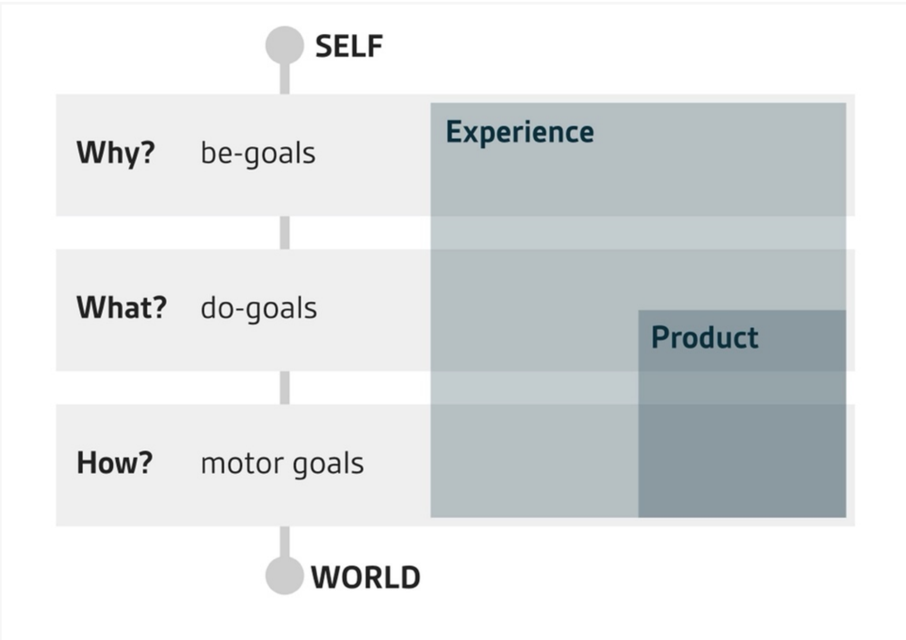
- The pragmatic dimension of user experience (sometimes called "ergonomic"; Hassenzahl, 2001; or "instrumental" UX; Thüring & Mahlke, 2007) concerns instrumental or utilitarian aspects and typically focuses on effectiveness and efficiency in reaching a specified goal (Burmester et al., 2002). Typically, perceived usability is included in the pragmatic dimension[4] (Hartson & Pyla, 2012; Lallemand et al., 2015).
- The hedonic dimension of user experience focuses on aspects beyond these instrumental or utilitarian considerations (Diefenbach et al., 2014a; Hassenzahl & Tractinsky, 2006), such as aesthetics (Diefenbach et al., 2014a) or emotions like joy of use (Diefenbach et al., 2014a;

[3] These terms refer to three general paradigms of HCI. The first concerns engineering and human factors, emphasizing the idea of a coupling of humans and technology. The second concerns usability, striving to make human interactions with technology more efficient. The third concerns user experience as outlined here (Harrison et al., 2007).

[4] I deliberately use the term "perceived" usability here to emphasize that usability typically includes a mixture of objective measures (e.g., completion rates or time on task) and subjective measures (e.g., satisfaction ratings), while UX typically focuses on subjective and often qualitative measures.

Hammer et al., 2018; Hassenzahl et al., 2001). The distinction between the pragmatic and hedonic dimensions also captures different goals in using technology. Fig. 8 describes different levels of goals (Hassenzahl, 2010). At the lowest level, *motor goals* refer to "how" to perform a particular action, such as creating a link in a concept map (Hassenzahl, 2010). At the middle level, *do-goals* refer to "what" the intended outcomes of interaction with technology are, for example, creating a concept map (Hassenzahl, 2010). Usability is primarily concerned with these do-goals, as it focuses on an instrumental goal and the series of actions needed to achieve it (Hassenzahl, 2010). At the top level, *be-goals* refer to the deeper reasons "why" interaction with technology happens, for example, wanting to gain competencies in a particular topic area (Hassenzahl, 2010). These reasons are necessarily subjective and depend on individuals' identities (hence the spectrum from the objective "world" to subjective "self"), but are the drivers behind their actions (Hassenzahl, 2010): A student decides to create a concept map because it will help them increase their competence. Be-goals are assumed to be closely related to psychological needs (Hassenzahl, 2008). Given the high importance of these be-goals, several papers in the present dissertation investigate the be-goals of digital concept mapping (Chapters 2, 3, and 4).

Fig. 8*: Different levels of goals according to Hassenzahl (2010)*



Recently, researchers in HCI have increasingly focused on the eudaimonic dimension as another potential candidate to define user experience (Mekler & Hornbæk, 2016). The notions of hedonia and eudaimonia relate to different ways of achieving well-being. Hedonic approaches try to achieve well-being through the pursuit of pleasure and joy (Huta & Waterman, 2014). Eudaimonic approaches try to achieve well-being through the pursuit of deeper human goals, such as achieving excellence, finding meaning, or acting according to one's ideals (Huta & Ryan, 2010; Huta & Waterman, 2014).

Mekler and Hornbæk (2016) have shown that eudaimonic experiences with technology exist. These eudaimonic user experiences are closely related to learning, particularly in connection to important personal goals (Mekler & Hornbæk, 2016). Interestingly, pragmatic quality is often closely associated with eudaimonic user experiences (Mekler & Hornbæk, 2016). Consequently, several scholars have suggested including eudaimonia as another dimension of user experience (Hammer et al., 2018; Kamp & Desmet, 2014; Mekler & Hornbæk, 2019). The relationship between the hedonic and eudaimonic dimensions of user experience still needs to be further investigated. Some researchers have suggested positioning them on a spectrum (Niess & Woźniak, 2018), while others view them as two distinct roads to happiness: through pleasure (hedonic) or through "the good life" (eudaimonic; Desmet & Hassenzahl, 2012). These roads might in turn be associated with different psychological needs: the need for pleasure seems to be closely related to the hedonic dimension, while needs like competence and self-actualization seem to be closely related to the eudaimonic dimension (Deci & Ryan, 2000; Hammer et al., 2018; Huta & Ryan, 2010). Recently, Peters et al. (2018) have suggested the Motivation, Engagement, and Thriving in User Experience (METUX) model to guide design for well-being, based on psychological needs (rather than the distinction of pragmatic and hedonic dimensions). The METUX model is currently gaining attention to analyze UX for well-being, for example for digital health services (Wannheden et al., 2021).

1.3.2.4 Why UX is Important: Reducing Cognitive Load and Creating Positive Experiences

UX to reduce extraneous cognitive load

First, UX is important because it allows learners to invest their mental resources into relevant aspects of a learning or assessment task (Hollender et al., 2010; Weinerth, 2015). Thus, the pragmatic dimension of UX is important for learners to maximize their performance on digital concept mapping, in line with cognitive load theory (CLT). CLT emphasizes that human working memory is limited and technology design needs to consider these limitations (Hollender et al., 2010). Specifically, CLT posits that different kinds of cognitive load exist:

- *Intrinsic cognitive load* refers to the complexity inherent in any topic, instructional material, or task (Hollender et al., 2010; Sweller, 1994), such as the fact that learners need to master several aspects simultaneously as part of a task.
- *Extraneous cognitive load* refers to complexity derived from the instructions, task, design, or other aspects that need to be processed by learners but do not directly contribute to learning (Hollender et al., 2010; Sweller, 1994).
- *Germane cognitive load* refers to complexity that is beneficial for learning and assessment purposes (Hollender et al., 2010; Leppink et al., 2013), for example, because learners need to actively integrate new information into existing schemata.

The focus of design is to reduce extraneous cognitive load (Amadieu et al., 2015; Hollender et al., 2010; Sharp et al., 2019), for example, by designing a digital product that is easy to use (Hartson & Pyla, 2012; Hollender et al., 2010; Norman, 2013; Oviatt, 2006; Sharp et al., 2019). Reducing extraneous cognitive load might be particularly important for a complex task like concept mapping (Amadieu et al., 2009; Sanchiz et al., 2019). For example, Weinerth (2015) found that learners using a usability-optimized concept mapping tool significantly outperformed learners using a baseline concept mapping tool in a concept map-based assessment. Thus, designing usable tools is a prerequisite for fair assessment (Tselios et al., 2008; Tselios et al., 2001; Weinerth, 2015). Consequently, the International Guidelines for Computer-Based and Internet-Delivered Testing by the International Test Commission (ITC) (2006) require usability testing as part of the development of digital assessment tools.

UX to create positive experiences in education

Second, a digital tool might contribute to creating positive experiences in learning and assessment. The pragmatic dimension of UX is primarily concerned with solving problems related to human interactions with technology to avoid negative emotions (like frustration) and ultimately lead to satisfaction (Desmet & Hassenzahl, 2012; Hassenzahl, 2010; International Organization for Standardization [ISO], 2018). However, having no negative emotions and being satisfied is not equivalent to having positive emotions and experiences (Hassenzahl, 2010; Hassenzahl, 2003; McCarthy & Wright, 2004). Thus, solving problems related to human interaction with technology can be understood as a path from a negative to a neutral state, not to a positive state (Desmet & Hassenzahl, 2012).

The hedonic dimension of UX is primarily concerned with positive aspects of human interactions with technology (Bargas-Avila & Hornbæk, 2011). Designing for user experience explores possibilities rather than problems (Desmet & Hassenzahl, 2012). Such possibility-driven design holds the potential to meaningfully shape humans' use of technology. Hassenzahl (2010, p. 31, italics in original) describes this potential as follows:

> Deliberately designed experience should be *positive*. However, this is not meant as a call for a world of "infinite jest" and shallow amusement. A better term for positive, thus, may be "worthwhile" or "valuable." Positive experiences are *per se* worthwhile, because they fulfill universal psychological needs. Negative experiences, however, can be worthwhile too, if they allow for a higher, valuable end.

Various empirical research findings emphasize the importance of positive experiences for learning and assessment (Pekrun, 2011). For example, positive emotions are related to feelings of well-being (Lyubomirsky et al., 2005; Tien et al., 2018), raise motivation (Edelmann, 2000; Efklides et al., 2006; Lewis et al., 2009), enhance learning (Masters et al., 1979; Tien et al., 2018), and influence assessment (Carpenter et al., 2013; Fredrickson, 1998; Isen et al., 1985; Lyubomirsky et al., 2005). Research on the impact of these positive emotional experiences has mainly focused on the design of instructional materials (Heidig et al., 2015; Plass et al., 2014). However, as education becomes more digitalized, technology itself will contribute to students' experiences with learning and assessment. One of the original contributions of the present dissertation is to add to research on creating positive experiences in digital education. Digital concept mapping is a particularly useful case study for this research objective because the experiential component of concept mapping has rarely been researched, as the following section will demonstrate.

User experience in digital concept mapping as a research gap

In their International Guidelines on Computer-Based and Internet-Delivered Testing, the International Test Commission (ITC) (2006, p. 147) suggested that designers and developers should "[c]onduct adequate usability testing of the system requirements using the appropriate delivery platforms to ensure consistency of appearance and delivery". Is this advice systematically followed when it comes to digital concept mapping? A systematic literature review on usability in concept map-based assessment by Weinerth et al. (2014a) provides reasons to doubt this. Based on 24 academic articles that met the inclusion criteria, the authors concluded that "the relevance of the insights in research on human-computer interaction has not yet been fully considered" (Weinerth et al., 2014a, p. 206). Several scholars acknowledge that learners need to master digital concept mapping tools, but see adequate training as a solution (Gouli et al., 2003; Jonassen et al., 1997; Weinerth et al., 2014a). Studies exploring usability in concept mapping are scarce (Pirnay-Dummer et al., 2010; Tao, 2015). A dissertation by Weinerth (2015) systematically investigated usability in concept mapping. In addition to the systematic literature review mentioned above (Weinerth et al., 2014a), Weinerth examined usability in user tests and a field study. Learners with a usability-optimized version of the concept mapping tool obtained significantly higher scores than learners with a baseline version (Weinerth, 2015). These results emphasize the need to investigate usability, as also recommended by the International Test Commission (ITC) (2006). However, usability-related aspects are only one component of user experience. In particular, non-instrumental qualities of user experience are not examined in the aforementioned research.

Research on the non-instrumental components of user experience with respect to digital concept mapping is scarce. Some researchers have reported learners' subjective impressions and emotions. For example, Heinze-Fry and Novak (1990) and Simone et al. (2001) reported survey results from learners who used concept mapping in a course. These learners had positive subjective impressions of their learning effectiveness and feelings regarding the experience of concept mapping. Chiou et al. (2015) found that multimodal animated concept maps enhance learning satisfaction. Erdogan (2009) found some evidence that computer-based concept mapping might enhance attitudes towards computers. Some researchers have explored learners' thought processes during concept mapping with think-aloud protocols (Ghani et al., 2017; Hilbert & Renkl, 2007). For example, Hilbert and Renkl (2007) identified different kinds of learners with respect to concept mapping, suggesting that combining the activities of planning the concept map and carefully labeling the relations increases learning success. Digital concept mapping's promise to allow insights into concept map creation processes might make it possible to design concept mapping tools that promote activities beneficial for learning. For example, Wang et al. (2019b) presented a concept mapping system that supports beneficial cognitive processes when learning with texts and concept maps. Finally, a few studies in HCI have investigated concept mapping from a design perspective, for example, with respect to defining gestures for creating concept maps on tabletops (Baraldi et al., 2006) or annotating video lectures with concept maps (Liu et al., 2018). However, although studies like those mentioned above investigate some experiential aspects of concept mapping (e.g., subjective impressions, emotions, or cognitive processes during concept map creation), there have not yet been any systematic investigations of user experience in concept mapping. The present dissertation contributes to closing this research gap.

1.3.2.5 How to Consider UX: Qualitative Research and Human-centered Design

As the objective of the present dissertation is to investigate and design for a positive user experience in digital concept mapping, the final questions to consider are methodological: How can user experience be measured, and how can a positive user experience be designed for?

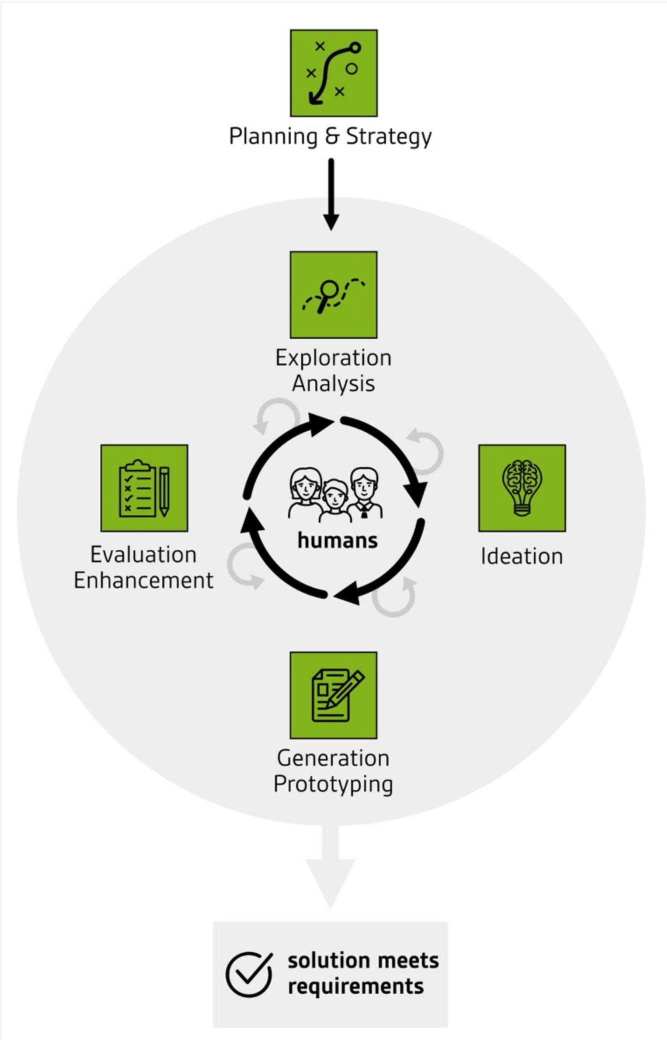
With respect to the former question, UX evaluation methods typically emphasize the subjective nature of UX and are often qualitative (Bargas-Avila & Hornbæk, 2011; Hassenzahl, 2010), although various quantitative, standardized measurements of user experience also exist, like the User Experience Questionnaire (UEQ; Laugwitz et al., 2008) or the AttrakDiff (Hassenzahl et al., 2003). Usability typically focuses on a combination of objective measurements, like task completion time and error rate, and subjective measures like satisfaction ratings (Hornbæk & Law, 2007; Koenig, 2006). Observational methods like user tests are also highly valuable in UX research, as they make it possible to observe interactions with prototypes in realistic settings (Lallemand & Gronier, 2018). The present dissertation will implement a mix of methods and triangulate the results.

Regarding the latter question, various approaches to design for a positive user experience exist. Several guidelines and design books exist, for example, usability heuristics (Nielsen, 1994), general-purpose usability and user experience books (Jacobsen & Meyer, 2019; Krug, 2014), or design books for specific purposes like gestural navigation (Saffer, 2008). However, for a research project like the present dissertation, a systematic approach is needed to ensure that users' specific needs in specific contexts are adequately covered. HCI typically builds on an approach known as user-centered design (UCD) or human-centered design (HCD). The terms "user-centered design" and "human-centered design" are often used synonymously (International Organization for Standardization [ISO], 2019; Lallemand, 2015), although in principle, "human-centered" is the broader term because it also covers experiences by non-users, e.g., external stakeholders (International Organization for Standardization [ISO], 2019). Human-centered design is defined as an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" (International Organization for Standardization [ISO], 2019, definition 3.7). Hassenzahl (2010) proposed the term "experience design" to describe design approaches aimed at shaping experiences. Experience design means to consider experiences before a product: It refers to a shift in perspective that calls for understanding how every aspect of a product shapes experience instead of thinking of the product in the first place (Hassenzahl, 2010). However, human-centered design and experience design are very close conceptually (Lallemand, 2015). Both design approaches share the core ideas of involving humans often and early in the process, thoroughly testing any idea, and iteratively improving solutions (Hartson & Pyla, 2012; Jacobsen & Meyer, 2019; Lallemand & Gronier, 2018).

In the present dissertation, I will use the terms user-centered design, human-centered design, and experience design synonymously to refer to the design process that inspired the creation of our digital concept mapping tool. In particular, my approach is based on recommendations by the International Organization for Standardization (ISO) (2019), the "wheel" process suggested by Hartson and Pyla (2012), and the UX design process suggested by the University of Luxembourg's HCI department, described in Lallemand and Gronier (2018). Fig. 9 presents an overview of this design process:

- Humans are positioned at the core of the design process. Their feedback serves as the foundation for specifying requirements for the digital concept mapping tool. Humans can be involved in different roles, namely as users, testers, informants, and design partners in co-design (Druin, 2002; Sanders & Stappers, 2008). The present dissertation includes humans in all of these roles, as it involves testing real usage situations (Chapter 11), testing prototypes (Chapters 7 and 8), providing information about experiences and psychological needs (Chapters 4, 8, and 11), and co-designing use contexts and design ideas (Chapters 2 and 3).
- User experience design typically consists of different phases (see Fig. 9). The *planning and strategy phase* concentrates on defining a UX design project's general objectives and resources. The *exploration and analysis phase* concentrates on understanding users' requirements. The *ideation phase* concentrates on creating ideas for meeting the identified requirements. The *generation and prototyping phase* concentrates on realizing prototypes of the design ideas. The *evaluation and enhancement phase* concentrates on evaluating the created prototypes with participants from the target audience (Hartson & Pyla, 2012; Lallemand & Gronier, 2018).
- The outlined UX design process is iterative: Results from each phase, particularly user feedback, are used to refine requirements, design ideas, and prototypes in an ongoing way. These subjective impressions by users are interpreted as opportunities to design for better experiences (Hassenzahl, 2010). The process is repeated until a solution is found that meets all identified requirements.

Fig. 9: *User experience design process in the present dissertation*

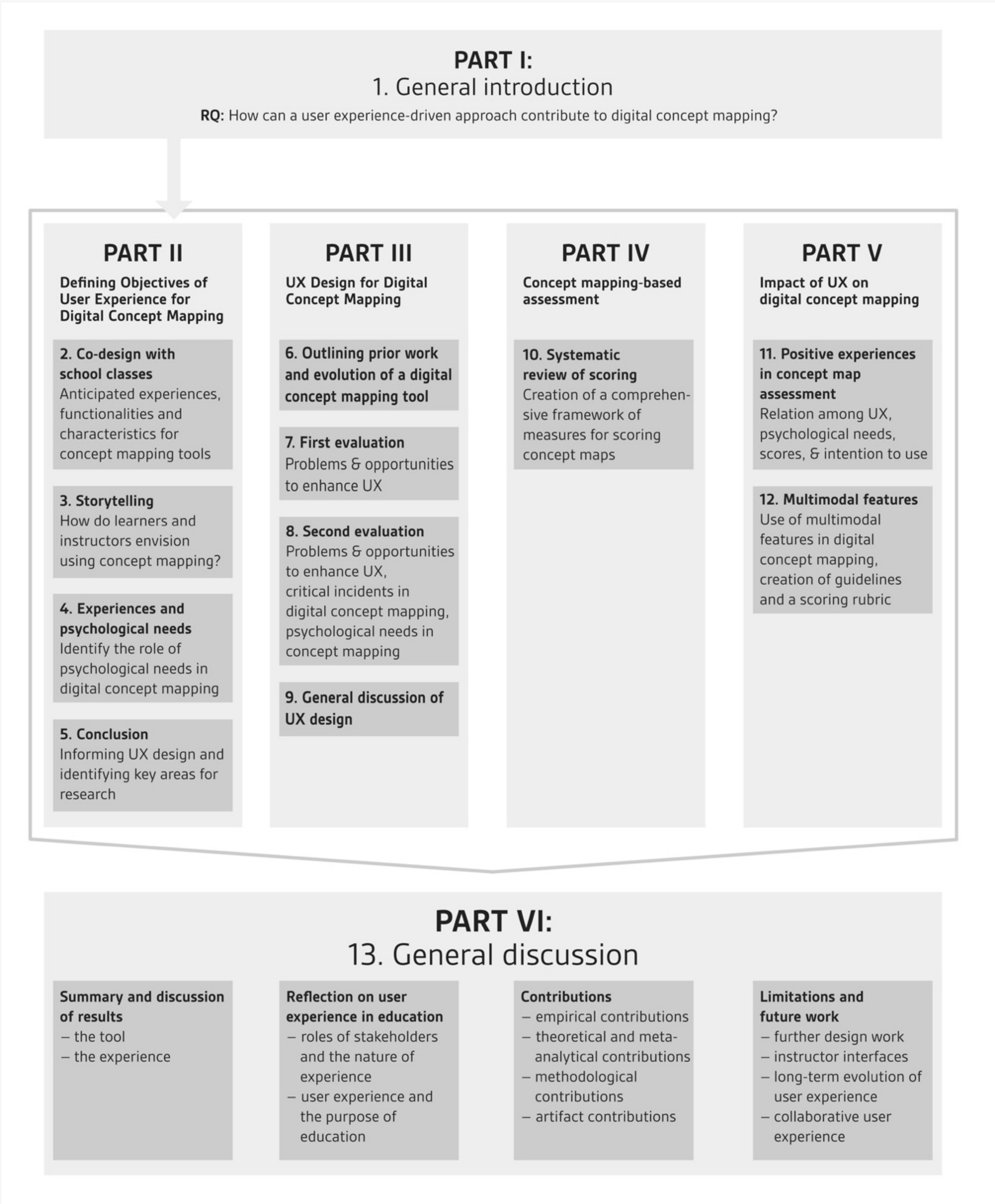


Human-centered design is a key component of the present dissertation. All reported studies served a double function. First, they addressed particular research objectives. Second, they were part of different phases of a human-centered design process to inform and validate the design of a digital concept mapping tool. In the following section, I will outline the individual studies and relationships between them.

1.4 Outline of the Dissertation

This dissertation is the result of a collaboration of SCRIPT, an institution of the Luxembourgish government to enhance education, and the University of Luxembourg. Besides the research-related outcomes, it addresses the creation of a digital concept mapping tool. This tool is intended to be introduced in Luxembourgish institutions of secondary education and will also be implemented in OASYS, an online assessment platform created at the University of Luxembourg. This project is also connecting to a sister project, School Futures, that addresses systems thinking in Luxembourgish education (Raber, 2021). Fig. 10 presents a high-level overview of this dissertation.

***Fig. 10**: Outline of the present dissertation*



- Part II presents three studies that define main objectives of user experience design (UX design) for digital concept mapping. First, Chapter 2 presents a full paper on a co-design approach for anticipated experiences based on a field study in four classes. Second, Chapter 3 presents a storytelling study to define how digital concept mapping could be integrated into schools in Luxembourg. Third, Chapter 4 presents a study on experiences with knowledge visualization and the role of psychological needs in digital concept mapping. I wrap Part II up by integrating my findings into a prioritization of requirements for subsequent work (Chapter 5).

- Part III presents studies on UX design for digital concept mapping. It addresses the research objective of systematically researching and enhancing UX regarding digital concept mapping. First, Chapter 6 describes prior work in design and development of the digital concept mapping tool. Second, Chapters 7, 8 and 9 describe the evolution and evaluation of three digital concept mapping prototypes. Furthermore, Chapter 8 covers both momentary (during concept mapping) and episodic user experience (after concept mapping; Roto et al., 2010) to deeply investigate how the design of concept mapping tools impacts concept mapping experiences.
- Part IV presents a full paper encompassing a systematic literature review of scoring concept maps (Chapter 10). The scoring of concept maps was identified as a major challenge for instructors and researchers in Part II. Although several earlier papers provide overviews of concept map scoring, their results only partially overlap. Thus, Chapter 10 systematically investigated criteria used to score concept maps and integrated the findings into a comprehensive framework and guidelines.
- Part V presents studies on the impact of UX on digital concept mapping. It addresses the research objective of contributing to the establishment of UX in digital concept mapping by demonstrating its impact and showcasing how UX might contribute to advancing the field of digital concept mapping. First, Chapter 11 presents a full paper on a quantitative field study investigating the relations between psychological needs, UX, intention to use, and scores obtained in digital concept mapping. Second, Chapter 12 presents a work-in-progress paper on the role of multimodal features in digital concept maps. These features have been frequently suggested in user research, but there are no concrete guidelines for their use in concept mapping. Thus, three workshops were conducted, which served as a foundation for constructing materials on how to meaningfully use multimodal features in digital concept maps. Building on these workshop results, earlier findings, and theoretical considerations, guidelines and a scoring rubric are proposed.

After these main studies, Part VI presents a general discussion (Chapter 13). It summarizes and discusses the results, reflects on the notion of user experience in light of my findings, outlines the contributions of this dissertation, and identifies limitations and opportunities for future work.

PART II:

Defining Objectives of User Experience for Digital Concept Mapping

2 Experience Matters: Bridging the Gap Between Experience- and Functionality-driven Design in Technology-enhanced Learning

Abstract

With the growing importance of digital technologies in learning and assessment, it is important to consider user experience (UX) to ensure that tools provide useful functionalities for learning without overwhelming users, to motivate users and ensure that they have positive learning experiences, and to allow users to realize their potential with the help of technology. Building on a case study of concept mapping for technology-enhanced learning, we combined experience-driven and functionality-driven approaches in co-design sessions in four school classes (67 students). We investigated the anticipated experiences that students imagined as well as the functionalities and characteristics they expected. We found that combining experience-driven and functionality-driven approaches is a valuable method for improving technology-enhanced learning.

2.1 Introduction

Education today faces tremendous challenges posed by societal, economic, ecological, and technological change. Learning and assessment are increasingly mediated and shaped by digital technology. Technology in education is at the core of technology-enhanced learning (TEL), in which technology is used to meet pedagogical needs. The success of this attempt depends on whether humans understand how to use technology for learning purposes. For example, a tool for technology-enhanced learning could potentially offer beneficial functionalities, but these might overwhelm the human user if they impose too much cognitive load that would be ineffective for learning (Leppink et al., 2013; Sweller, 2010). Furthermore, if a tool for technology-enhanced learning does not provide positive experiences such as enjoyment, learners' motivation to continue learning might be affected (Wang et al., 2019a). Accordingly, every aspect that shapes learning success has to be considered when designing tools for technology-enhanced learning.

One field that is concerned with investigating how technology shapes human experience is human-computer interaction (HCI). HCI investigates how humans and technology interact in reference to clearly defined sets of needs that have been identified. HCI has a long tradition in integrating users in the design and development process (e.g., in usability evaluation, user-centered design, or co-design; Muller & Druin, 2012). User experience (UX) has recently emerged as a key trend in HCI research (Krannich et al., 2012; Lallemand & Koenig, 2017).

This paper describes a co-design case study in the field of technology-enhanced learning involving a concept mapping tool. As concept mapping is an effective learning method (Schroeder et al., 2018), it is crucial to design a tool that can effectively support learners in concept mapping. Employing the concepts of usability and user experience, the current study was aimed at combining functionality-driven and experience-driven approaches in co-design sessions to obtain a complete picture of what learners expect from a concept mapping tool. The paper involves empirical data collected from four classes of students. We found that the combination of a functionality-driven and an experience-driven co-design approach can help researchers reveal important aspects that need to be considered in designing tools for technology-enhanced learning.

2.2 State of the Art

2.2.1 Usability, User Experience, and Co-design

With the rise of digital technologies in every facet of life, including the emergence of technology-enhanced learning, the importance of HCI has grown in recent decades. Research on HCI has long focused on investigating what technology does (the "what" of technology or "do-goals") along with how humans interact with it (the "how" of technology or "motor goals"; Hassenzahl, 2010). Likewise, creating technology involves identifying which functionalities it should include and measuring how successful it is in providing these functionalities. Usually, one of the success factors is usability, defined as the effectiveness, efficiency, and satisfaction of achieving a goal (Burmester et al., 2002).

Usability and its associated criteria are well-suited for the design and evaluation of concrete functionalities that users rely on while interacting with a given technology. Usability has thus been the most dominant concept in the designing of technology for many years and has contributed to shaping an approach that provides considerable attention to concrete functionalities. Whereas functionality-driven design and usability remain important, the perspective of HCI has expanded in recent years, moving to a "third wave of HCI" (Bødker, 2006) or "third paradigm of HCI" (Harrison et al., 2007) with a stronger emphasis on user experience (UX; Lallemand & Koenig, 2017). UX describes the human experience with technology from a holistic viewpoint and includes usability (Burmester et al., 2002). Besides the so-called pragmatic aspects ("do-goals" or the "what" question of experience), UX is equally concerned with hedonic aspects ("be-goals" or the "why" question of experience; Hassenzahl, 2008) that go beyond the instrumental (Hassenzahl & Tractinsky, 2006). Whereas interest in the hedonic aspects of UX has grown rapidly (Diefenbach et al., 2014a), Mekler & Hoernbæk recently investigated eudaimonic experiences (striving toward the best) as another dimension (Mekler & Hornbæk, 2016). For example, in a fictional online course about data science, pragmatic aspects might be comprised of the lessons, exercises, and search functionalities. Hedonic aspects might be comprised of motivational messages, virtual certificates, or making the exercises enjoyable. Eudaimonic aspects might be comprised of elements referring to the overarching goal of building a career as a data scientist (e.g., by aligning different courses with a suggested learning path).

All of these UX dimensions are highly relevant to technology-enhanced learning. Regarding the so-called pragmatic aspects, the focus is on a tool's functionalities and characteristics for technology-enhanced learning. Thus, functionality-driven design is about specifying what a product should do. Regarding the hedonic (e.g., motivation, positive learning experiences) and eudaimonic aspects (e.g., realizing one's potential, achieving happiness or one's ideals), however, the investigation has to move beyond this functionality-driven approach. Experience-driven design is about understanding the above-mentioned "why" question of design to discover which experiences a tool should provide (Olsson et al., 2013). Furthermore, experience-driven design investigates UX at different points in time (Roto et al., 2010), that is, anticipated UX (before using the tool), momentary UX (while using the tool), episodic UX (after using the tool), and cumulative UX (over time). All of these are equally important from the perspective of humans using technology. Thus, an approach that integrates functionality-driven (pragmatic) aspects with experience-driven (hedonic and eudaimonic) aspects is promising.

The role of the human as a reference point for the design of adequate experiences is essential across all stages of the design process: They can act as informants, designers, testers, and users (Druin, 2002). User-centered design emerged as a key methodology in HCI research and typically concentrates on "humans as subjects" (Sanders & Stappers, 2008). Humans are greatly involved throughout the process but mostly as subjects in observations and interviews. However, research in HCI has long investigated the other roles that humans can play as well. Accordingly, it has a long tradition in co-design (Sanders & Stappers, 2008), where humans suggest design ideas in addition to providing insights and testing prototypes.

Based on the idea that everybody is creative (Jung-Joo et al., 2018), co-design has a wide range of advantages for the user-centered design of technology-enhanced learning tools. It democratizes design (Smith et al., 2017) because it allows participants to take an active role in dealing with today's educational challenges, fitting well into an "era of participation" (Smith et al., 2017) with ever-increasing demands for 21st-century skills (Binkley et al., 2012). Thus, co-design provides an excellent opportunity to match the functionalities of technology-enhanced learning tools with learners' real interests. Therefore, in this case study, we investigated a co-design approach that invited participants to create their ideal tool for technology-enhanced learning and to explain why it might help them with learning and assessment.

2.2.2 Concept Mapping in Technology-Enhanced Learning

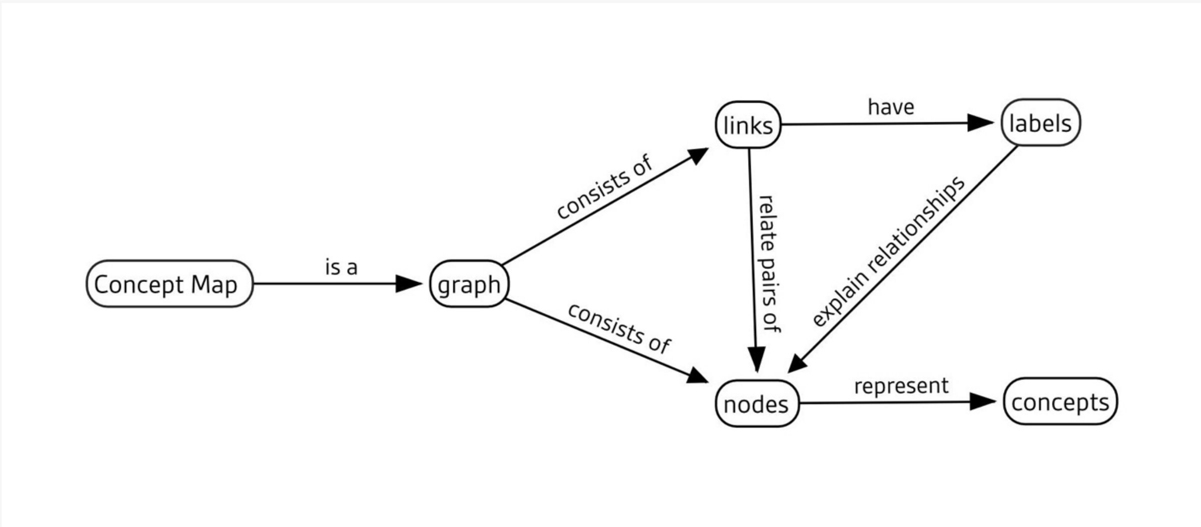
We selected the design of a concept mapping tool to use in a case study in which we combined an experience-driven and a functionality-driven co-design approach in technology-enhanced learning. Concept maps are visual representations of knowledge (Novak & Gowin, 1984) that make the relations between various parts of a topic or process explicit. They use concepts inside shapes (nodes) with labeled links that can be directed or non-directed. A pair of concepts form a proposition that specifies their semantic relation. Thus, concept maps are node-link diagrams (Schroeder et al., 2018) that are similar to other types of visual representations used in education (e.g., mind maps or knowledge maps).

They are used for many purposes in learning and assessment (e.g., unrestricted concept mapping, providing key terms for concepts and labeled links, or leaving blanks in a concept map that students should fill in; Cañas et al., 2012; Strautmane, 2012). Many studies have explored the learning benefits of concept maps (Nesbit & Adesope, 2006; Schroeder et al., 2018). They differ from well-known mind maps (Buzan & Buzan, 2010) by explicitly showing the relations between connected concepts with the help of link labels (Eppler, 2006), making them a more structured approach for the visualization of knowledge (Davies, 2011).

Concept mapping is a compelling case for technology-enhanced learning for several reasons. First, concept mapping is a promising approach for the learning of 21st-century skills because of its potential to promote meaningful learning (Novak, 2010), critical thinking in complex systems (Brandstädter et al., 2012), sustainability (Segalàs et al., 2010), and interdisciplinarity (Reiska et al., 2018). Second, technology-enhanced concept mapping offers several advantages over paper-and-pencil-based concept mapping, particularly because of its greater flexibility in adding multimodal attributes such as color, images, or fonts to a concept map (Kim & Olaciregui, 2008), easier correction of errors (Erdogan, 2009), and availability of a variety of scoring methods (Strautmane, 2012). Third, regarding summative assessments (Dixson & Worrell, 2016), concept mapping allows for a variety of tasks, such as identifying errors in concept maps (Aguiar & Correira, 2014), creating maps around a focus question (Cañas & Novak, 2006), or investigating the effects of collaborative concept mapping on individual learning (Chen et al., 2018b). Finally, regarding formative assessment (Dixson & Worrell, 2016), concept mapping is a promising method for investigating knowledge construction over time (Trumpower & Sarwar, 2010).

Furthermore, co-design has the potential to advance the method and the tools involved in concept mapping. For example, research has found that students who self-generated concept maps during learning performed worse than students who used concept maps that were provided to them, potentially caused by the higher cognitive load imposed by the poor usability of a demanding tool (Colliot & Jamet, 2018). Usability is a crucial factor in concept mapping as students using a usability-optimized tool outperformed students using a baseline version (Weinerth, 2015). However, usability has rarely been considered in concept mapping research (Weinerth et al., 2014a). Thus, we collected evidence of what learners expect from a concept mapping tool to provide a solid foundation for a user-friendly design.

Fig. 11: *Example concept map (Weinerth et al., 2014a)*



2.3 Research Questions

We conducted a case study of a concept mapping tool in which we combined experience-driven and functionality-driven approaches in technology-enhanced learning. The first research question concentrated on students' anticipated experiences. Their anticipated experiences included hedonic and eudaimonic aspects (e.g., basic needs that the tool should address, hopes for advantages that it might afford, motivations for using it, contextual factors such as the hardware supporting the tool, and the emotional aspects accompanying its use). These aspects provided the foundation of what users expected to experience. Afterward, the second research question concentrated on the pragmatic functionalities and characteristics that students expected from a concept mapping tool to realize their anticipated experiences. We defined anything that the tool was supposed to do (e.g., saving) as "functionality" and any general attribute of the tool (e.g., an aesthetic design) as a "characteristic."

1. *Research Question 1*: Which anticipated experiences do students communicate in their co-design artifacts (hedonic and eudaimonic aspects, the "why" question)?
2. *Research Question 2*: Which functionalities and characteristics do students envision for a concept mapping tool (pragmatic aspects, the "what" question)?

After answering these research questions, we relate the anticipated experiences to the functionalities and characteristics in the discussion section, pointing to the areas that require further investigation in research and design. Accordingly, this study contributes to bridging the gap between the functionality-driven and experience-driven design of technology-enhanced learning tools.

2.4 Methodology

2.4.1 Participants

Four classes with 67 students from Luxembourg participated in the co-design sessions. All classes had a similar age range, but they came from three different socioeconomic settings. Table 1 presents the descriptive details of the classes.

Table 1: *Classes participating in the co-design study*

Session	School	Participants
I	Private Catholic secondary school	22 (ages 18-19)
II	Private Catholic secondary school	11 (ages 17-18)
III	Technical secondary school	15 (ages 17-19)
IV	Classical secondary school	19 (ages 17-18)

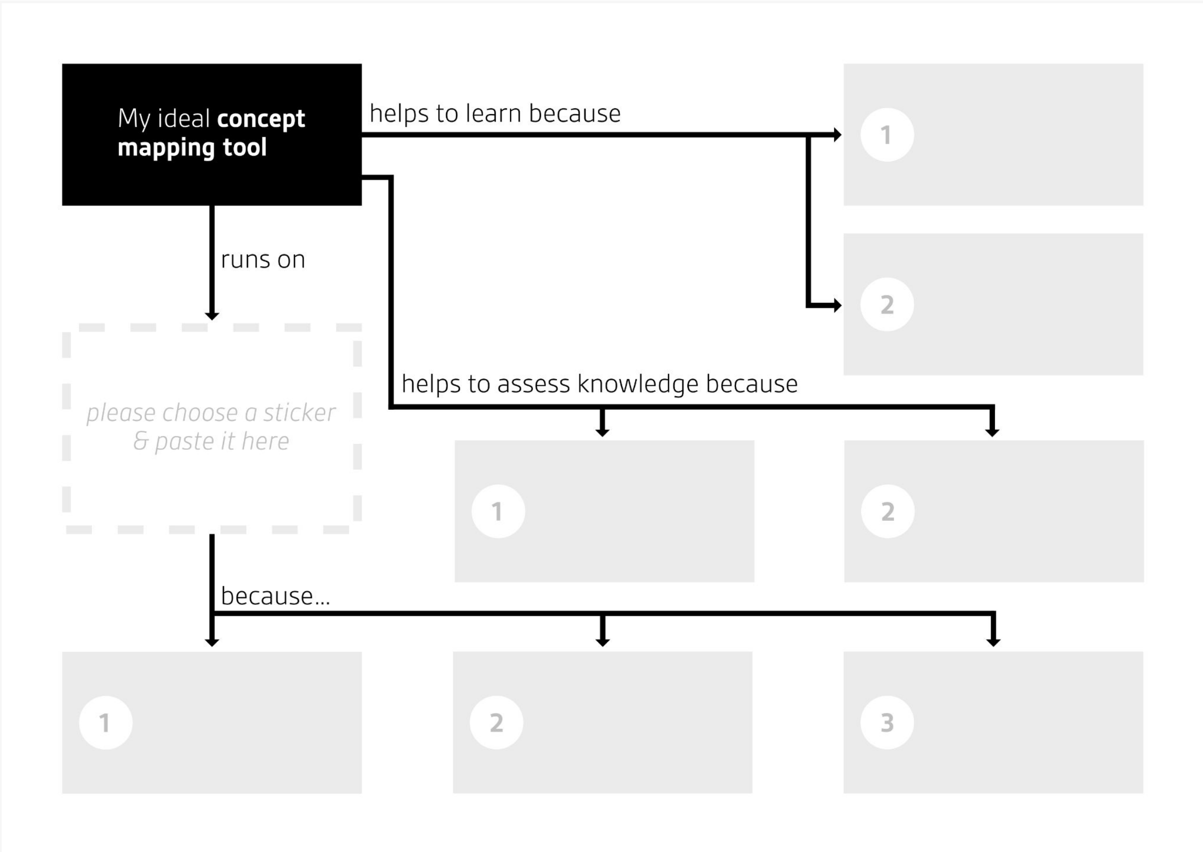
2.4.2 Materials & Setting

The co-design sessions took place in 90-min lessons during regular school hours. We chose regular classrooms to facilitate student participation and to purposefully observe the actual context where the tool will be used (Muller & Druin, 2012). However, this decision implied that the environment of the study was less controlled in comparison with our lab facilities. Accordingly, some adjustments to our settings were necessary regarding ethics, background knowledge, and co-design approach. The research project obtained ethical approval from the University of Luxembourg's Ethics Review Panel (ERP 18031). Both the APA Ethical Principles & Code of Conduct and the UXPA Code of Conduct were consulted in planning the study. All the materials and instructions were pretested in two additional classes that did not participate in the study.

Regarding ethics, the challenge consisted of safeguarding the strict requirements of (informed) consent in a setting where students were required to be present in class. We thus first collected written informed consent from the students (and their parents when the students were minors) who wanted to participate. Afterward, we distributed the answer sheets independently and explicitly pointed out that students were free not to return them if they did not want to participate. Furthermore, collecting informed consent and answer sheets independently ensured the anonymity of the data, making it impossible to connect the answer sheets to the participants' names.

Regarding background knowledge, we made sure that every student had sufficient knowledge about the topic from the co-design session (concept mapping). First, we introduced the students to concept mapping by explaining its characteristics. Specifically, we compared concept maps with mind maps because students were already familiar with mind mapping. We explained the differences between concept maps and mind maps and provided them with three examples of concept maps. Students were allowed to ask questions. We used a fill-in-the-blank concept map about their ideal concept mapping tool (see Fig. 12). This template allowed students to experience concept mapping even if they had no previous experience with the method. The template prompted them to select a hardware device (e.g., a computer or tablet), provide reasons for their choices, and explain why concept mapping could help them in learning or knowledge assessment. This template allowed us to collect data about their anticipated experiences (Research Question 1, the "why" question) because it asked the participants to imagine the experience of using a concept mapping tool while at the same time explaining the reasons behind the experiences they identified as valuable.

Fig. 12: *Fill-in-the-blank mapping template*



Regarding the co-design approach, we carefully devised the approach that was best suited for collecting the students' design ideas. Building on their anticipated experiences regarding the concept mapping tool, students were invited to form groups after a short break to co-design their ideal tool. The groups were told they should think about which functionalities and characteristics (Research Question 2, the "what" question) would be necessary for the experiences they anticipated they would have, but they were also free to include other ideas they considered important. The co-design activity was a 3-12-3 brainstorming (Gray et al., 2010): First, students were invited to discuss in groups of 2 to 4 students what an ideal concept mapping tool should look like for 3 min.[5] Second, they should choose one of their ideas and sketch a possible solution.[6] The researcher stressed that every form of representation that they considered appropriate for conveying their ideas was allowed. The co-design phase lasted for 12 min. Table 2 provides an overview of the co-design artifacts the students created during this phase. Finally, each group presented their ideas by showing and explaining their sketches to the class. Students from the other groups were invited to ask questions and discuss their ideas either publicly or by commenting on the answer sheets. Each group had 3 min to present their ideas. Overall, the co-design session lasted for roughly 30 to 35 min with an additional 10 min for debriefing. During the presentations, the researcher took notes on his observations to facilitate the analysis.

***Table 2**: Co-design artifacts created in the collaborative sessions*

Group	Artifact	Description
I-1	App icon & first screen	Concept mapping app "Easy learning" with personal login
I-2	Text in bullet points	Multifunctional app (e.g., course plan, chatting, scanner, calculator, concept map)
I-3	Several drawings of features and interactions	Concept mapping tool with different interaction styles (voice, pen, icons)
I-4	Entire user interface	Software with graphical user interface and pop-ups
I-5	Elements of user interface & text	Multifunctional tool (e.g., course plan, chatting, broadcasts of courses, concept map, books)
II-1	Drawings & texts describing features	Various options for the designing of concept maps, access control, multiple languages
II-2	Entire user interface with example concept map	Software with graphical user interface & concept map with different design options (shapes, border styles, font sizes)
II-3	Example concept map & text	Concept map with different design options (colors, shapes, font styles)
II-4	Concept map of tool features & aspects	Various aspects of a concept mapping tool (options, user interface, design)
II-5	Device (tablet) & text	Tablet app with voice recognition and personalization options
II-6	Entire user interface, individual screens & text	User interface on desktop & smartphone screen with personalization options
III-1	Entire user interface, example map & text	Software with graphical user interface & concept map

[5] The instructions were: "Please discuss what your ideal tool for learning with concept maps should look like: Which functionalities should it have, what should it look like, which other characteristics would be important for you?"

[6] The instructions were: "Select one of your ideas and create a sketch of it (e.g., of the interface, a person or group interacting with the tool, a certain functionality or what it does)."

III-2	Fragments of user interface & text	Multifunctional tool (e.g., calculator, dictionary, periodic system, concept maps)
III-3	Several drawings of features and elements of user interface	Multifunctional tool with external sources integrated into concept maps, export functions
IV-1	Several successive app screens	Step-by-step drawings of smartphone app with motivational features
IV-2	Elements of user interface, drawings of devices & example map	Multifunctional pen (microphone, fingerprint sensor) to digitize analog maps while drawing, several toolbars, example map with different design options
IV-3	Elements of user interface & text in bullets	Multifunctional social network for students with concept map navigation
IV-4	Elements of user interface & text	Concept mapping tool with design options & integration of search engine results
IV-5	Entire user interface, device & text	Learning tool dealing with problems in chemistry with a concept map
IV-6	Entire user interface & text in bullets	User interface on smartphone with personalization options and design features

2.4.3 Analysis

After the classroom sessions, the answer sheets were collected, digitized, and analyzed in the MaxQDA software for qualitative data analysis. We followed a qualitative content analysis approach and performed a summarizing content analysis (Mayring, 2002) regarding students' anticipated experiences (Research Question 1) and the functionalities and characteristics they expected (Research Question 2). We went through every artifact and inductively placed the anticipated experiences and functionalities and characteristics into categories. When appropriate, we subsumed them under existing categories. We reconsidered and verified the categorization system after the first two classes, applied it to the remaining classes, and verified it a second time, making sure that we did not miss any aspect. As outlined in the preceding section, we designed the "fill in the blank" concept maps to point our participants toward anticipated experiences and the co-design artifacts to point them toward functionalities and characteristics. However, participants sometimes mentioned functionalities or characteristics in their fill-in-the-blank concept maps and vice versa. Thus, we coded both the fill-in-the-blank concept maps and the co-design artifacts for both research questions.

2.5 Results

In the following, we first present the anticipated experiences that participants reported (i.e., the "why," Research Question 1); in a second step, we report the ideas about functionalities and characteristics the participants imagined (i.e., the "what," Research Question 2). In the tables, we distinguish between the fill-in-the-blank activity (method M1) and co-design studio groups (method M2). A total of 67 students participated in the study, with a total of 67 fill-in-the-blank concept maps. The students then broke into a total of 19 groups (of 3 to 4 students on average), which each provided one co-design artifact. The numbers in the tables specify how many of the fill-in-the-blanks or co-design artifacts mentioned the result. Examples of verbatim responses were translated from German by the first author.

2.5.1 The Why: Anticipated Experiences with a Concept Mapping Tool

Participants' anticipated experiences covered which hardware device they preferred for a concept mapping tool and the learning and assessment aspects afforded by concept mapping. These were mainly derived from the fill-in-the-blank concept maps (M1), although some additional points were found in the co-design artifacts as well (M2).

2.5.1.1 Preferred devices for a concept mapping tool

Regarding the preferred devices for the tool, no clear trend was found: There were 28 votes for computers (41.8%), 34 for tablets (50.7%), and some additional votes for both platforms (2 votes; 3%), paper (2 votes; 3%), or smartphones (1 vote; 1.5%). Reasons for computers were efficiency ("it is faster to type on or to select something"; "the screen is bigger"), versatility ("you can format the tool more easily"), precision ("mice and keyboards are more precise than the screen on a tablet"), or ease of use ("I can deal with it better"; "I have been using it since I was young"). Reasons for tablets were portability ("it is handy"; "I can take it with me anywhere and learn anytime"; "I have everything in one place instead of having 1,000 sheets of paper"), touch screen ("it is more precise because you can draw with a pen"; "I can easily make the image bigger or smaller"), and ease of use ("it is more practical because it has a touch screen"; "it is easy to use"; "it is easier to work with than a mouse and keyboard"). Based on preferences for both devices, the concept mapping tool should be optimized for both computers and tablets with their respective input modalities.

2.5.1.2 Anticipated experiences regarding learning and assessment advantages afforded by concept mapping

Participants anticipated a variety of experiences (see Table 3), particularly regarding structuring complexity, learning how to learn with the help of concept mapping, and assessing knowledge.

Table 3*: Anticipated experiences with a concept mapping tool in fill-in-the-blank concept maps (M1) and co-design artifacts (M2) (number of times mentioned in the artifacts)*

Category	Functionalities or characteristics	M1	M2
1) Structuring complexity	Structure, orderliness, good overview, clear arrangement	40	3
	Collect and summarize topics or ideas	2	
	Greater efficiency in communicating knowledge in collaboration	2	
	Compare maps with others	2	

	Discover new aspects or connections through mapping	1	
2) Learning how to learn (efficiency)	More efficient learning	17	1
	Appropriateness for different subjects	5	2
	Crossing borders between subjects and topics	3	
	Fun while learning	2	
3) Learning how to learn (sustainability)	Advantages of visual aspects of concept maps	18	
	Learning benefits from mastering the method of concept mapping	8	
	Learning benefits from creativity	2	
4) Assessment	Greater efficiency in communicating knowledge in tests	5	
	Opportunity to judge how people use what they know	1	
	Specify importance of concepts and links in maps (weighted concept map)		1

Structuring complexity was found to be a very prominent anticipated experience for students with respect to concept mapping (i.e., Category 1 in Table 3). Accordingly, many of the fill-in-the-blank answers (M1) expressed the desire to get a better overview for oneself (“it gives me a better overview”; “everything at one glance”; “it is more orderly”) or to be able to communicate knowledge more efficiently in collaboration (“you can more easily share and compare concept maps”).

Learning how to learn with the help of concept maps was another prominent anticipated experience, particularly in two areas: the efficiency of learning and the sustainability of it (i.e., Categories 2 and 3 in Table 3). First, regarding the efficiency of learning, participants expressed that concept mapping might make learning faster and easier (“it reduces the material to the essential and you only have to learn the most relevant aspects”) or more enjoyable (“other than a text, it is visually more attractive”; “it is fun to create a concept map, and therefore it is fun to learn”). In addition, participants expressed that concept mapping might be a learning approach appropriate for different subjects, potentially even demonstrating relations between subjects (“you can easily summarize the different subjects”). Second, regarding the sustainability of learning, students expressed that the visual nature of concept maps might help them retain knowledge (“I can remember things better visually”). The reasons they communicated were either that the method might be a useful alternative to other learning methods (“it is something new, and it might connect school and learning better”; “it is individual, a personal learning method”) or that the spatial arrangement might add another modality to learning (“the visual nature makes it easier to remember words because you remember where they were located”).

Regarding the assessment of knowledge (i.e., Category 4 in Table 3), participants expressed that concept maps can help them identify whether they know something or not (“it becomes immediately clear whether you have understood something”). However, many participants left the assessment blanks unanswered, provided very general answers (“it is explicit”; “it is logical”), or expressed doubts (“assessment is limited because it is hard to connect topics”). These results indicate that even though students consider concept maps to be a valuable assessment method, they also need substantial guidance on how to use them.

2.5.2 The What: Functionalities and Characteristics of Concept Mapping

Four categories were extracted to organize ideas about functionalities and characteristics (see Table 4): ideas concerning the user interface, freedom and creativity, collaboration inside the typical school setting, and assessment of knowledge. Whereas most ideas for functionalities and characteristics were expressed in the co-design artifacts (M2), some were found in the fill-in-the-blank activities as well.

2.5.2.1 Easy-to-use and aesthetic user interface optimized for input modalities

Several of the ideas communicated in the co-design artifacts concentrated on the characteristics of the user interface (i.e., Category 1 in Table 4). First, the user interface was expected to be clear, simple, and user-friendly. However, qualities of the user interface also included hedonic aspects such as an aesthetic and stimulating design, a nice app icon, and motivational messages to support the learning process.

Second, the user interface ideas mentioned a range of specific functionalities such as help and search functionalities, localization of the user interface, and personalization (e.g., by selecting tools for the toolbar or by changing the color scheme; see Fig. 13).

Third, the user interface ideas showed an awareness of differences between specific input modalities. In particular, ideas included the strong wish to draw concept maps by hand or with a pen on tablets ("it is more precise than a computer if you draw with a pen"; "you can develop your own creativity by drawing with your hand"; see Fig. 13), multitouch gestures on tablets ("it is easier to make a picture bigger or smaller"), or dragging and dropping elements from another window into the concept map.

2.5.2.2 Freedom and creativity that help learning with concept maps

A variety of ideas focused on specific functionalities aimed at aiding learning, mainly concerning aspects of freedom and creativity (i.e., Category 2 in Table 4). Twelve co-design artifacts showed options for creativity in choosing fonts, colors, line styles and thicknesses, or a variety of shapes. In addition, ideas included the opportunity to enrich concept maps by adding other media (images, videos, audio files) or to integrate external sources into the maps. Furthermore, aspects of freedom could be seen in ideas such as the ability to run offline or to open several maps at the same time for comparison and in an interface that would allow students to start maps on their own, without the teacher granting access. Finally, several ideas focused on language functionalities (e.g., auto-translation or dictionaries). These ideas would allow students to create their maps in any language they preferred, a finding that reflects the multilingual situation in the country of study.

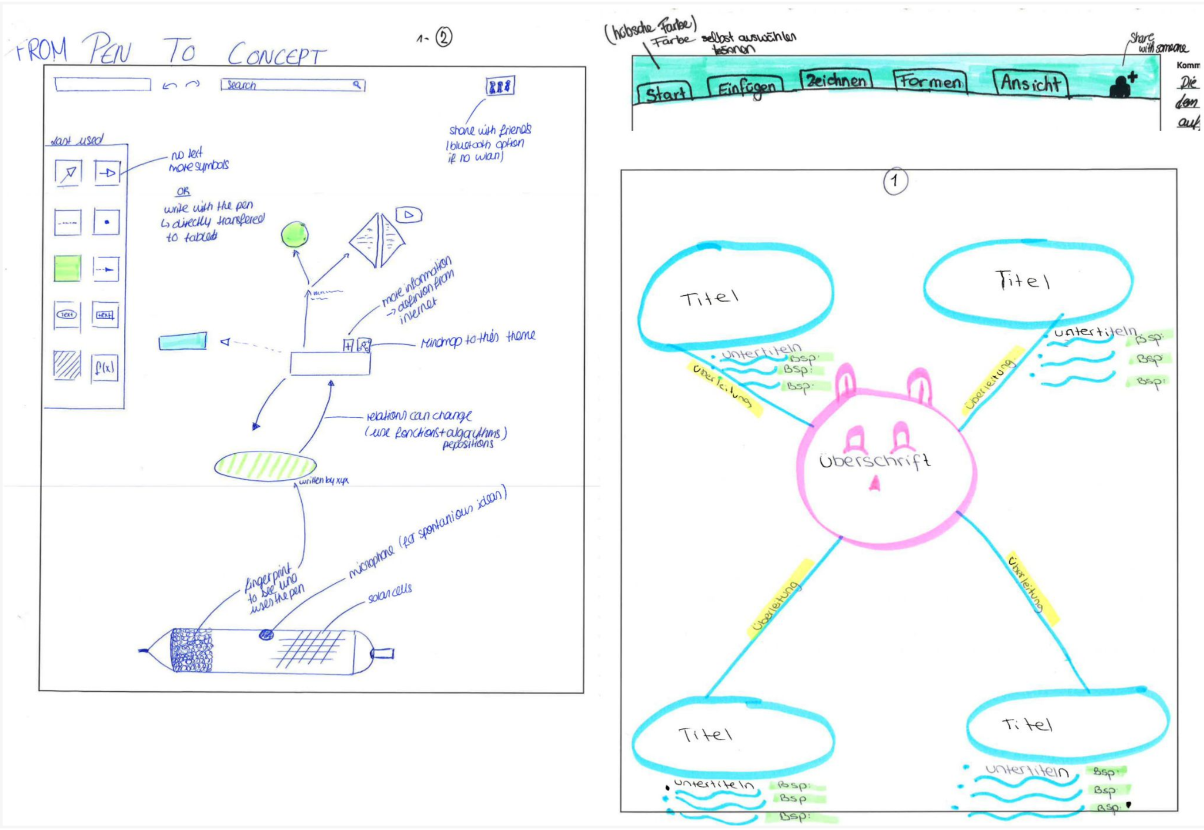
***Table 4**: Functionalities and characteristics of a concept mapping tool in fill-in-the-blank concept maps (M1) and co-design artifacts (M2) (number of times mentioned in the artifacts)*

Category	Functionalities or characteristics	M1	M2
1) User Interface	Clear, simple, intuitive user interface	7	7
	Drawing with hand or pen on a tablet	5	6
	Personalization of user interface		8
	Simple, useful search function	1	3
	Provide help functionalities	1	3
	Personalization of map background		2
	Interface localization		2
	Drag & drop		2
	Aesthetic app icon		2
	Aesthetic design	1	
	Motivational messages		1
2) Freedom & creativity	Multiple design options for maps	2	24
	Integrating external data sources	7	4
	Language functions (auto-correction, dictionary)	2	6
	Learn wherever you are	4	
	Have all learning materials in one place	3	
	Functionality of judging the trustworthiness of external sources	2	
	Undo & redo		2
	Offline mode	1	
	Open & compare several maps at the same time		1
	Create maps independently of teacher		1
	Opportunity to nest maps (submaps)		1
	Provide templates that set relevant options		1
	Grid or guiding lines to position elements		1
	Legend to explain the meaning of design options		1
	Specify importance of concepts and links in maps (weighted concept map)		1
	Auto-save		1
	Share maps with others	2	4

3) Collaborative school settings	Individual accounts		6
	Export & print functionalities		4
	All-in-one application integrating concept maps with other tools		3
	Rights management		2
	Chat or comment function		2
	Public cloud with maps		1
	Synchronous collaboration in one document		1
	Track changes by person		1
4) Assessment	Self-assessment	5	
	Learn from mistakes & knowledge gaps	2	2
	Features to practice before tests	1	1

Whereas this study was not aimed at systematically investigating the roles that freedom and creativity play in concept mapping, the results still offer some evidence on how participants imagine they would use creative options. Four of the student groups deliberately used a concept map to communicate their ideas (cf. Fig. 13). These concept maps use creative options in a meaningful way to distinguish between different categories of concepts or between broader concepts and examples. In addition, one co-design artifact explicitly included a functionality where students could create a legend that explained the meaning of their design choices.

Fig. 13: Pen drawing with adaptable toolbar (left, from Session IV), personalization of user interface colors (top right, from Session II), meaningful use of design options to distinguish content (bottom right, from Session II)



However, besides the variety of creative options, participants also suggested functionalities that would deliberately limit or guide their freedom in creating concept maps. Among these was the use of templates that limit the options for meaningful choices, grid lines to automatically position concepts, or the nesting of maps into submaps that can be revealed if needed. In addition, safety functionalities such as undo/redo or the auto-saving of maps were mentioned frequently.

2.5.2.3 Concept maps in collaborative school settings

Another set of ideas pointed to the collaborative school setting where the concept mapping tool will be used (i.e., Category 3 in Table 4). Accordingly, the co-design artifacts included chat or comment functionalities, individual accounts for every student (including rights management and the tracking of changes when students collaborate on concept maps), and different ways of sharing concept maps (e.g., via social media, links, public cloud, printing, or exporting the map in various formats). Three groups combined the concept mapping tool with other functionalities such as calculators or the periodic system.

2.5.2.4 Assessment of knowledge with concept maps

Finally, a range of ideas about functionalities focused on the assessment of knowledge (i.e., Category 4 in Table 4), for both formative and summative assessment (Dixson & Worrell, 2016). Regarding formative assessment, participants investigated how the tool could provide feedback about learning progress to allow for self-monitoring (Sadler, 1989). Ideas included an interface suggesting areas for improvement ("when you write a concept map, it could show you how to make it better") or for specifying errors that participants made ("it shows me my errors"). Regarding summative assessment, ideas about functionalities tended to concentrate on preparing for exams ("additional, teacher-made exercises to prepare for tests").

2.6 Discussion

Investigating the fill-in-the-blank concept maps and the co-design artifacts provided insights into anticipated experiences and the functionalities and characteristics students expected from a concept mapping tool. Two aspects were particularly important for the generalizability of our results beyond this case study: the methods chosen and the relations between the experience-driven and the functionality-driven investigations.

2.6.1 Triangulation of Methods

First, the triangulation of methods is noteworthy. The study used a combination of individual fill-in-the-blank concept maps and collaborative co-design sessions, which revealed different, yet complementary results. Unsurprisingly for a learning tool, most of students' anticipated experiences in the fill-in-the-blank concept map concentrated on aspects of effective learning and the assessment of knowledge (the "why" question). Frequent topics were being able to better structure knowledge visually and more efficient learning. The co-design artifacts, on the other hand, much more prominently communicated functionalities such as creative options, hedonic features of personalization and self-expression, and collaborative features (the "what" question). Neither method was able to reveal the entirety of the results without the other.

Accordingly, the evidence suggests that combining experience-driven and functionality-driven methods of data collection is a valuable approach for obtaining more nuanced and complete specifications of tools for technology-enhanced learning. For example, it is striking that the fill-in-the-blank concept maps emphasize aspects of competence, whereas the co-design artifacts emphasize aspects of creativity and self-expression. A possible explanation for this finding might be that the fill-in-the-blank concept map asked for an ideal concept mapping tool regarding aspects of learning, assessment, and technology. These questions could have primed participants to focus on aspects of competence. However, the co-design sessions equally asked participants to imagine their ideal concept mapping tool for learning. An alternative explanation might thus be that participants moved one step further when asked to actively imagine their ideal tool in their co-design artifacts: They included functionalities and characteristics that could realize their anticipated experiences (e.g., creative options to structure knowledge) while at the same time considering functionalities and characteristics that went beyond the building of competence (e.g., options for collaboration or for adjusting the user interface to their own preferences). Likewise, the fill-in-the-blank concept maps revealed anticipated experiences that participants did not cover in their co-design artifacts (e.g., for formative assessment), potentially because they did not know how.

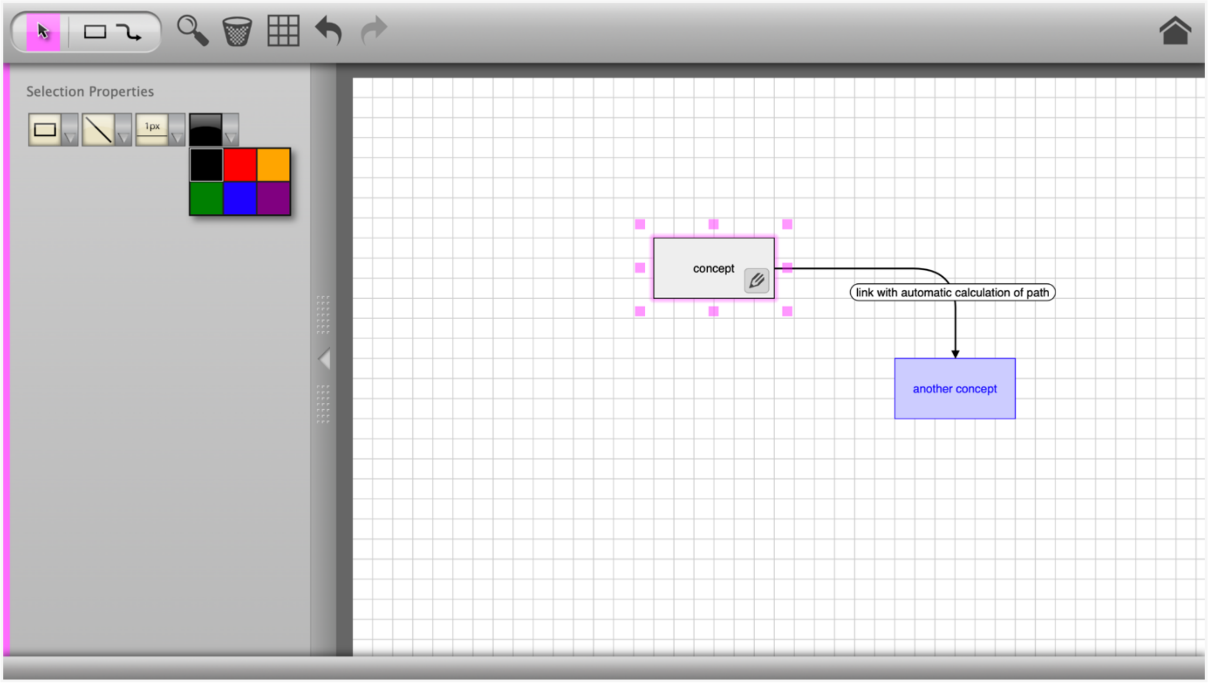
Although these individual results are limited to our specific case, the methodological idea of combining experience-driven and functionality-driven approaches applies to the co-design of other tools for technology-enhanced learning. It helps acquire a complete picture of what users expect from a tool for technology-enhanced learning.

2.6.2 Relations between Anticipated Experiences and Functionalities

Second, the study revealed a range of potential conflicts to consider when designing the concept mapping tool. The central aspects informed by the users were the structural organization of knowledge, efficient learning, and creativity. However, how these aspects are related is not entirely clear. In the example concept maps that students created in their co-design artifacts, they tended to use creativity functionalities in a meaningful way to structure knowledge (e.g., by specifying subtopics and categories of concepts). This observation raises interesting questions: Do these functionalities enhance learning with concept maps because they make the relations clear? How should these functionalities be included in concept map assessments, which tend to rely on the written content and the structural connections of maps (Strautmane, 2012)? However, it might also be the case that the creative feature hinders learning because students spend too much time on stylistic aspects (Miller et al., 2008), thus reducing the efficiency of learning. For example, adding multimedia elements to concept maps has a positive effect on the time spent with concept mapping and the coherence of the created maps, but it does not positively affect learning outcomes (Sanchiz et al., 2019). Thus, investigating how creativity functionalities and learning outcomes are related might help advance the method of concept mapping.

Furthermore, our findings raise important questions about balancing the aspects of usability and user experience in the design of the concept mapping tool. For example, Fig. 14 shows the interface of one of our tool prototypes. It offers a limited selection of design options (e.g., six colors that cannot be adapted by participants) and automatically calculates the closest path between connected concepts. Whereas this tool has already been extensively tested and optimized for usability and pragmatic aspects (Weinerth, 2015), the limited choices for its design options might interfere with students' need for creativity and the building of their individual knowledge structures as communicated by participants in this co-design study. Accordingly, it might be worthwhile to reconsider these design decisions in experience-based studies.

***Fig. 14**: Prototype with limited design options*



Another interesting question was posed by the observation that users anticipate the functionality of adjusting the user interface to personal preferences and a user-friendly, simplified interface at the same time. How should the design of the concept mapping tool balance these potentially opposing aspects? Should one be considered more important in designing technology-enhanced learning tools? These are difficult decisions for any designer to make, and only further research will be able to provide answers. However, knowing which areas to explore is a critical step in the design process. The methodological approach of this co-design case study in technology-enhanced learning has proven valuable in determining these research directions.

2.6.3 Limitations

Whereas conducting our study in the classrooms facilitated student participation, it also meant we had to respect strict time constraints. Because we could not interfere with regular school lessons, extensions were impossible. Accordingly, we left a substantial amount of buffer time and concentrated on the two data collection methods described in this case study. We made sure we strictly adhered to our instructions on concept mapping to guarantee that students gained sufficient knowledge about the topic. When we had additional time left, we led the students in activities that helped them learn even more about design, or we answered students' general research-related questions. We carefully defined and pretested how much time students could spend on the co-design activities. However, we could not rule out the possibility that students with more concept mapping experience or more time to create co-design artifacts might come up with additional ideas for functionalities and characteristics or anticipated experiences. Thus, we think that replicating the study with experienced students or with variations in the setting would be interesting despite the fact that our particular tool is targeted toward novice students.

It should be noted that communicating an idea about functionality does not necessarily mean that users will actually use it. Furthermore, there might be important functionalities that participants could not think of. In addition, frequently mentioned ideas might turn out to have less impact on user experience than rarely mentioned ones. Finally, anticipated experiences do not necessarily have to align with users' actual experiences when using the tool. For example, it might turn out that other experiences become more important in a real-use situation that students could not have imagined beforehand. However, user experience explicitly included anticipated user experience (Roto et al., 2010), making this solid ground from which to begin the design work.

Finally, there were fuzzy cases in which the distinction between an anticipated experience and a functionality or characteristic was not clear-cut. We used the definitions given in the research questions section as the basis for our decisions. Accordingly, we defined data relating to hedonic and eudaimonic aspects as "anticipated experiences" (e.g., why participants use a tool and which contextual factors such as emotions, motivations, or the situation in which the tool is used affect their experience). We defined data relating to pragmatic aspects as "functionalities or characteristics" (e.g., what the tool is supposed to do and the general characteristics it should have). However, a subset of our data might fall in between these categories. This is particularly true for the hardware choices where aspects of anticipated experiences (e.g., easier use with a touch screen) are closely related to functionalities (e.g., drawing maps with a pen). However, given that our main argument is that the combination of an experience-driven and a functionality-driven co-design approach is valuable, we do not view these fuzzy cases as a major issue for the validity of our results.

2.7 Conclusion

Building on a case study of co-design sessions for the design of a concept mapping tool, we investigated the combining of an experience-driven and a functionality-driven co-design approach in technology-enhanced learning. We demonstrated how anticipated experiences reveal answers to the "why" question about the tool, in particular the needs to structure complexity, enhance the efficiency and sustainability of learning, and improve assessment. Afterward, we found evidence for functionalities and characteristics that students expect from a concept mapping tool, in particular, an easy-to-use but aesthetic user interface, creative options, collaborative functionalities, and formative assessment. Finally, we demonstrated how anticipated experiences are related to the functionalities and characteristics of a tool, and we found interesting questions to address in the following design phase.

Whereas this case study investigated the design of a concept mapping tool, it has broader implications for the design of technology-enhanced learning. First, it demonstrated the usefulness of simultaneously investigating anticipated experiences as well as functionalities and characteristics. Both perspectives are necessary for a complete picture of what users expect from a tool for technology-enhanced learning.

Second, it revealed a range of ideas beyond pragmatic aspects, in particular, hedonic (e.g., aesthetic design or personalization options) and eudaimonic aspects (e.g., learning how to learn), all of which have the potential to positively affect learning success. In conclusion, combining experience-driven and functionality-driven design approaches has the potential to substantially enhance the quality of tools for technology-enhanced learning.

2.7.1 Acknowledgment

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3 From Stories to Experience Design: Exploring Situational Factors of Digital Concept Mapping With Storytelling

Abstract

Given the fundamental role of contextual factors in determining user experience, experience design has to systematically investigate the situations in which a digital product will be used. In contrast to other approaches of contextual inquiry, the present study suggests using co-creative storytelling. Storytelling involves participants directly in contextual research and empowers them to share their past, present, or envisioned experiences. Three focus groups with students and instructors from schools and universities (N = 14) were performed to investigate how participants envisioned integrating digital concept mapping in their educational activities and which desired outcomes and pain points they want to address. Results indicate a large variety of scenarios described in stories, covering individual and collaborative learning, teaching and instruction, as well as formative and summative assessment. Furthermore, stories and discussions revealed patterns of desired outcomes and pain points behind the described situations. The chapter concludes by discussing the contributions of these results to the design of digital concept mapping tools and the storytelling methodology.

3.1 Introduction

User experience can only be understood in context (Roto et al., 2010). Thus, designing for user experience means systematically researching the contextual factors that impact the use of a digital product. Hartson and Pyla (2012) use the term "ecological perspective" to describe these contextual factors. By ecological perspective, they are referring to "how the system or product fits within its work context, in the flow of activities involving it and other parts of the broader system" (Hartson & Pyla, 2012, p. 301). Thus, experience design needs to consider the ecological context in which a to-be-designed product will be used. Consequently, the current chapter explores the ecological context of digital concept mapping in the Luxembourgish educational system. It builds on a methodological combination of co-design-based storytelling to elicit ideas for using concept mapping and focus-group-based discussion to uncover the deeper desired outcomes and pain points behind the described experiences.

3.2 State of the Art

3.2.1 Storytelling for Experience Design and Research

Stories have a long tradition in design and UX research. Stories describe the plot of an imagined or real event in detail, usually building on elements like well-defined characters, a setting, and a plot structure (Ciriello et al., 2017; Gruen et al., 2002). Storytelling is the act of communicating these events with stories (Ciriello et al., 2017). Several types of stories are used in design and UX research:

- *Scenarios* are "rich stories of interaction" (Dix et al., 2003, p. 201) that describe an activity by outlining the flow of events and actions to fulfill a goal (Ciriello et al., 2017; Gruen et al., 2002; Rosson & Carroll, 2001; Wende et al., 2014).
- *Storyboards* combine textual and visual representations of the interaction (Dix et al., 2003; Hartson & Pyla, 2012; Truong et al., 2006).
- *Use cases* are detailed descriptions of the sequence of user interaction with technology, typically using a short series of steps in bullet points (Ciriello et al., 2017; Wende et al., 2014).
- *User stories* describe the features of a digital product from the perspective of a user, usually based on the questions "who" (different roles of users), "what" (features or characteristics of a digital product), and "why" (reasons for having a particular feature or characteristic; Wintersteiger, 2013). An example of a user story is "As a learner (*who*), I want to provide a legend for my use of shapes in a concept map (*what*) so that I can explain their semantic meaning (*why*)."

The lines between these terms are often blurry and not easy to distinguish (Gruen et al., 2002). In the present study, I adopted the general-purpose terms "story" and "storytelling" because I invited participants to create stories of any form. Furthermore, I adopted the term "scenario" to describe the overall goal of a story, for example, to facilitate collaborative learning. Scenarios were intended to provide the general framing for the individual stories.

Typical purposes of storytelling in UX design are specifying requirements and communicating visions of a future (Ciriello et al., 2017; Clausen, 1994; Gruen et al., 2002). Regarding specifying requirements, stories are typically derived from field research (e.g., contextual inquiry) and stakeholder interviews (Lallemand & Gronier, 2018; Rosson & Carroll, 2001; Truong et al., 2006). Regarding communicating visions of a future, stories allow designers to communicate the idea behind a technology, product, or service they are creating. Thus, they establish a basis for exchanging ideas with potential users (Clausen, 1994). In summary, stories enhance the communication between the users and designers or developers of a digital product (Ciriello et al., 2017; Wende et al., 2014). They can help build a shared understanding (Ciriello et al., 2017), thus ensuring a human-centered approach.

3.2.2 Co-creative Storytelling in Experience Design

As outlined above, storytelling is well established in human-computer interaction, but it is typically a researcher or designer who creates the stories (Kankainen et al., 2012). Users usually serve as informants who share their experiences and opinions with the designer or researcher (Druin, 2002). However, users can also be involved as design partners in a project (Druin, 2002). Such an approach is typical for co-creation, co-design, and participatory design. *Co-creation* describes any activity where creativity is applied collectively to solve a problem, in particular in the domains of businesses where customers turn into co-creators of value (Jung-Joo et al., 2018; Prahalad & Ramaswamy, 2004; Sanders & Stappers, 2008). *Co-design* refers to applying "collective creativity as it is applied across the whole span of a design process" (Sanders & Stappers, 2008, p. 6). Co-design, thus, is a subtype of co-creation. *Participatory design (PD)* has a long tradition in HCI as an approach to "put together the expertise of the systems designers/researchers and the situated expertise of the people whose work was to be impacted by the change" (Sanders & Stappers, 2008, p. 7). PD and co-design share the idea of empowering users to propose ideas for the design of digital products (Kankainen et al., 2012), but PD has a stronger focus on the political and structural dimension beyond the digital product, for example, by promoting democracy or investigating structures of organizations (Hansen et al., 2019; Kankainen et al., 2012; Muller & Druin, 2012).

The present study is a co-creation study that brings potential users of a digital concept mapping tool together to share their ideas. Such a co-creation approach has several advantages. Instead of focusing on the creativity of experts or designers, it embraces the creativity of all humans, in particular non-experts (Sanders & Stappers, 2008). Thus, it contributes to democratizing design by directly involving users in creating digital products that will ultimately impact their lives (Muller & Druin, 2012; Smith et al., 2017). This involvement can create long-term engagement (Smith et al., 2017). Furthermore, societal, technological, and economic trends like crowdsourcing, social media, and sharing economy have contributed to higher expectations of being involved in creating digital products (Smith et al., 2017).

A key element of co-creation activities is to provide humans with appropriate methods to express their ideas (Sanders & Stappers, 2008). I argue that storytelling is such an appropriate method for several reasons. First, storytelling is readily available without prior training or specific skills. Second, storytelling focuses on experience rather than technology (Gruen et al., 2002). In fact, experiences have often been described as identical to stories (Hassenzahl, 2010; Peng & Martens, 2018). Furthermore, stories can communicate past experiences or anticipated future experiences, making the method capable of covering several time frames of UX (Roto et al., 2010). These considerations make storytelling particularly compelling in a user experience-centered project like the present dissertation. Third, storytelling serves what Parrish (2006, p. 73) calls an "investigative function": Stories serve to reflect on which aspects are particularly relevant for an experience imagined in a story. This investigative function makes stories useful to empower users in early user experience design (Kankainen et al., 2012), particularly when participants only have been rarely exposed to an involved technology. Fourth and finally, storytelling can be integrated into focus groups and allow users to discuss the described experiences (Kankainen et al., 2012). Such an approach encourages participants to tell their stories in their own words, thus accounting for the fact that stories need to be interpreted (Clausen, 1994). The discussions aim to "establish mutual learning among the various stakeholders" (Smith et al., 2017, p. 65) and hold the potential to identify hidden reasons behind the envisioned stories (Kankainen et al., 2012).

3.3 Research Questions

The present study used storytelling to empower participants to communicate how they imagine integrating digital concept mapping in their educational activities:

- *Research question (RQ) 1*: How do participants envision integrating digital concept mapping in their educational activities?
- *Research question (RQ) 2*: What are the pain points and desired outcomes explaining the integration of concept mapping in educational activities?

RQ 1 identifies details about the different usage scenarios for digital concept mapping, thus helping to better understand digital concept mapping inside its context, the external ecosystem (Hartson & Pyla, 2012) in which it is embedded. RQ 2 identifies the deeper reasons behind the experiences described in the stories, particularly pain points and desired outcomes. Pain points describe problems that users want to address. Frequently, pain points occur in moments of high emotional intensity (Pennington, 2016) and are, thus, an important part of experience (Kalbach, 2021). Desired outcomes refer to what users consider worthwhile in terms of experience (Kalbach, 2021). Thus, RQ 2 aims to identify two strategies to design for experience: to identify which negative aspects to avoid and identify which positive aspects to consider in design.

3.4 Methodology

I performed three focus groups where participants shared stories. Each focus group covered a different set of target users and stakeholders. I used a focus group approach because I expected the social exchange between participants to foster meaningful discussions about motivations and expectations behind the stories (Mayring, 2002).

The focus groups covered different target populations for digital concept mapping. Focus group 1 included students from a school (N = 3, technical track) who used concept mapping in a computer science project. Focus group 2 included students from a university (N = 3) from Bachelor and Ph.D. levels. Focus group 3 included instructors (N = 8). Five of the participants worked as instructors in three different secondary schools. The three schools covered different socio-economic backgrounds to represent the whole spectrum of secondary education in Luxembourg. The five school instructors acted as consultants for the present Ph.D. project and its sister project, School Futures, in a so-called "reference group" that regularly met to ensure that the instructor's perspective is adequately considered in the project. The remaining three instructors worked at a primary school and two universities. They were involved in the organization of the School Futures project. Given their deep involvement with this project, they did not create stories but participated in the discussions by asking questions.

Prior to the study, the setting, instructions, and materials were pre-tested in a focus group involving experts in HCI and digital education (N = 7). Pre-tests revealed three improvements that were implemented in the final study. First, some changes to the materials were suggested, for example, providing more examples of concept maps. Second, the setting originally included additional activities about an ideal concept mapping tool and psychological needs (Lallemand, 2015). However, the participants expressed that the sessions should be shorter with fewer activities and more discussions. Thus, I decided to focus on the storytelling activities and related discussions in the focus groups. The other activities were included in another study (Chapter 4). Third, I originally wanted to split participants into groups to create their stories. However, participants preferred to work on individual stories and discuss them in the group. Thus, I switched to individual storytelling with more room for discussions.

3.4.1 Procedure and Materials

The students in focus groups 1 and 2 participated during their spare time and were compensated with 40 €. The instructors in focus group 3 participated during one of the regular reference group meetings. As these are part of their working contract with the schools, they were not additionally compensated. In the beginning, the participants were provided detailed information about the study. After the informed consent[7], participants received a detailed introduction to concept mapping (cf. Appendix A), including a definition and five examples. The examples were purposefully chosen to cover different possibilities to use concept mapping:

- a network-like concept map about water, created by me,
- a hierarchical concept map about concept mapping from Hay and Kinchin (2006),
- a "fill-in-the-blank" concept map from Ruiz-Primo and Shavelson (1996),
- a causal diagram created by team members of the "School Futures" project, and
- a systems diagram explaining the "cobra effect" created by Bo Raber[8]

[7] I obtained additional informed consent from parents if participants were below the age of 18.

[8] The cobra effect describes a historical incident in India where an attempt to solve a problem led to worsening the problem. A region had a problem with a growing population of cobras. The governor attempted to solve the cobra problem by awarding money to kill cobras, but unintentionally created a "business model" that led to breeding cobras. Siebert (2003) used it as the title of a book on unwanted economic consequences by wrong incentives. See also episode 96 of the Freakonomics podcast: https://freakonomics.com/podcast/the-cobra-effect-a-new-freakonomics-radio-podcast/

After the introduction, participants engaged in a discussion of around 20-25 minutes to ask questions and share their personal experiences with concept maps.

After the discussion, participants engaged in the storytelling activity. I encouraged participants to create a story outlining how digital concept mapping could help in a particular educational activity of their choice. I deliberately did not specify whether stories were fictitious or based on real experiences to avoid limiting the imagination of participants. I provided them with five scenarios to choose from: individual learning, collaborative learning, teaching and instruction, formative assessment, and summative assessment. The scenarios were chosen to cover the range of uses of concept mapping (Nesbit & Adesope, 2013) and to provide an inspiring framing for "rich stories of interaction" (Dix et al., 2003, p. 201), but participants were free to combine scenarios or create their own. A template was provided to the participants to prepare their stories (see Fig. 15). There were no restrictions regarding the form of representation for a story (e.g., drawing, writing, or acting). After preparing the stories for around 15 minutes, each participant presented their stories and answered questions. Finally, participants engaged in discussing the advantages and disadvantages of the presented stories for 20 minutes. All materials were available in German, French, and English. Participants were free to decide on the preferred language for the focus group.

Fig. 15*: Template used to elicit stories describing the use concept maps*

3.4.2 Analysis

After the sessions, the storytelling templates were collected. The discussions were recorded and transcribed. Afterward, I analyzed templates and transcriptions in MaxQDA using a qualitative, inductive coding approach. In particular, I followed the procedures for qualitative summarizing content analysis suggested by Mayring (2002):

1. I examined each story transcript and paraphrased statements into summarizing codes, carefully making sure that no meaningful information was lost. I subsumed statements under existing codes only if they did not provide additional information; otherwise, I created a new code.
2. After finishing coding, I went through all stories and transcripts to check the codes and organize them into pain points, desired outcomes, and scenarios[9]. If appropriate, I combined close or overlapping codes.
3. I went through the codes and identified patterns to answer my research questions.

As a quality check, I performed this final step of pattern identification twice. In January 2019, I wrote all codes on post-its and created an affinity diagram (Holtzblatt et al., 2005) outlining their relations (Fig. 16). The codes were discussed several times in the following months with different stakeholders, for example, with project partners, developers, and researchers. I repeated the coding process a second time in February 2021 without referring to the original analysis and found that the identified patterns were similar to the original codes.

[9] Furthermore, I coded functionalities and characteristics of the digital concept mapping tools described in the stories. I have included these results in my requirements analysis (Chapter 5) but will not report them in this chapter because they are out of scope.

__Fig. 16__: Affinity diagram describing patterns of desired outcomes and pain points (created January 2019)

Direct quotes in the following results section were translated. The full transcripts of the focus groups are available in the online supplement of this dissertation (https://rohl.es/dissertation). Examples from the stories were redrawn and translated into English to keep the handwriting of participants confidential. Care was taken that the drawings match the originals as closely as possible.

3.5 Results

3.5.1 RQ 1: How do Participants Envision Integrating Digital Concept Mapping in Their Educational Activities?

Regarding the stories that explain how participants envision integrating concept mapping in their educational activities, participants created stories covering the full spectrum of scenarios. Stories increased in abstractness across the focus groups. The younger participants from focus group 1 often sketched concrete examples of concept maps as visual support to illustrate their oral descriptions. The older students from focus group 2 created storyboards or text in bullet points to illustrate various steps in their story. Finally, the instructors from focus group 3 covered a large diversity of forms in their stories, including concrete examples, written stories in bullet points, and abstract flowcharts or causal diagrams outlining educational processes. Table 5 provides an overview of the stories.

__Table 5__: Overview of stories

Group	Scenario	Story
Focus group 1 students (N = 3)	Student 1 formative assessment	**content**: printed “fill-in-the-blanks” concept map sheet, students have to identify kinds of characters (e.g., numbers, capital letters, punctuation

technical track school		marks…) from a set of given characters and fill them at the right places; similar to quiz **form**: visually represented as example "fill-in-the-blanks" concept map
	Student 2 formative or summative assessment see Fig. 17	**content**: skeleton concept map with a central term ("world war") and questions as propositions (e.g., "when?", "who?") to be completed by students **form**: visually represented as example skeleton map
	Student 3 individual learning	**content**: instructor distributes a concept map outlining key information about a topic after a series of classes, helps learners to prepare for summative assessments **form**: not represented visually, orally presented to group
Focus group 2 students (N = 3) university	Student 1 teaching in a classroom	**content**: instructor begins a new topic with a classroom activity, asks students what they know about the topic, collects their answers as a concept map on a whiteboard, students start discussing their ideas collectively **form**: written as text in bullet points
	Student 2 teaching in a classroom and collaborative learning see Fig. 18	**content**: instructor begins a new topic with a classroom activity, asks students to write ideas about the topic on a tablet or smartphone, ideas are transferred to a presentation screen, related ideas are automatically connected **form**: visually represented as storyboard
	Student 3 teaching in a classroom and individual learning	**content**: students have to write a story in class, receive a "fill-in-the-blanks" concept map to add words that came to their minds, finally write a story using these words **form**: visually represented as storyboard
Focus group 3 instructors from three different schools (N = 8[10])	Instructor 1 formative assessment see Fig. 19	**content**: instructor wants to support students in their learning, uses concept maps to help them identify their strengths and weaknesses, guides them to auto-monitoring their learning **form**: flowchart-like concept map outlining important steps in formative assessment
	Instructor 2 teaching in a classroom see Fig. 22	**content**: instructor uses a concept map or flowchart to explain how to systematically adapt a verb form to past tense in French by asking a series of questions (e.g., "is it a direct or indirect object?"), illustrates using examples until students mastered the topic **form**: two example flowchart-like concept maps outlining grammatical processes (e.g., adapting a verb form to past tense in French)
	Instructor 3 teaching in a classroom	**content**: instructor uses concept maps to identify current knowledge of students, works towards reaching a particular learning goal, but constantly adapts teaching depending on student progress (might include switching to another learning goal, for example, because a certain competence is missing) **form**: abstract causal diagram outlining the central "current state" and three goals (represented by different icons); every element is interconnected in all directions

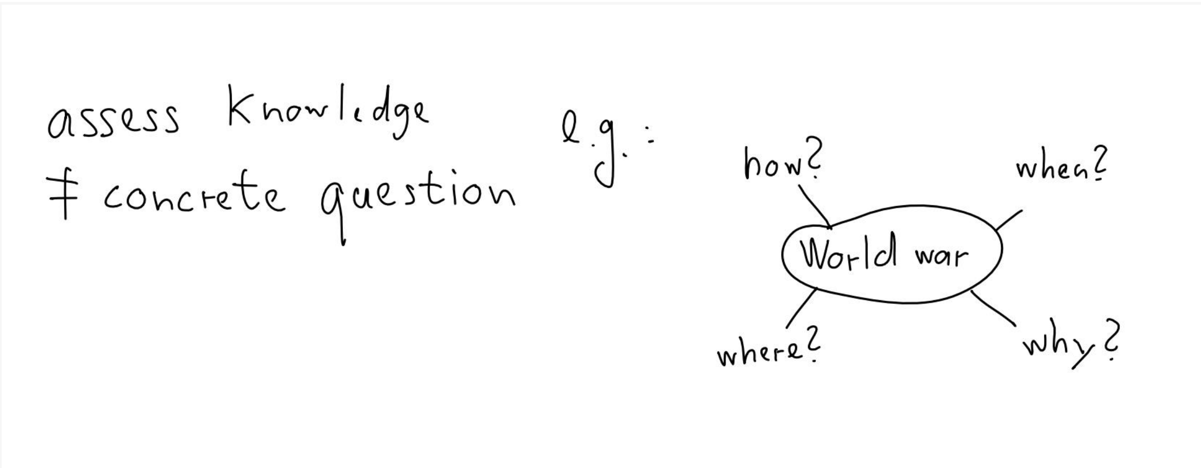
[10] Five participants created stories; three additional participants participated in the discussions.

Instructor 4 teaching in a classroom	**content**: instructor gives students homework to prepare a particular topic, students create concept maps about their homework in the following session, instructor demonstrates relations with the help of concept maps **form**: written as text in bullet points
Instructor 5 formative assessment	**content**: instructor plans 1-2 classroom sessions for active learning before a summative assessment; students create concept maps for 10 minutes; instructor shares & discusses some of the concept maps; instructor gives feedback and points to misconceptions or knowledge gaps **form**: written as text in bullet points

Regarding the content of stories, the younger students in focus group 1 were concerned about good grades. Their stories focused on the scenarios of formative assessments and learning. These scenarios inspired them to envision how concept mapping might help them prepare for summative assessments. One participant suggested that the instructors prepare summarizing concept maps for their students, but other participants thought that the students should create them on their own because “otherwise it is only rote learning“ (student 1, focus group 1).

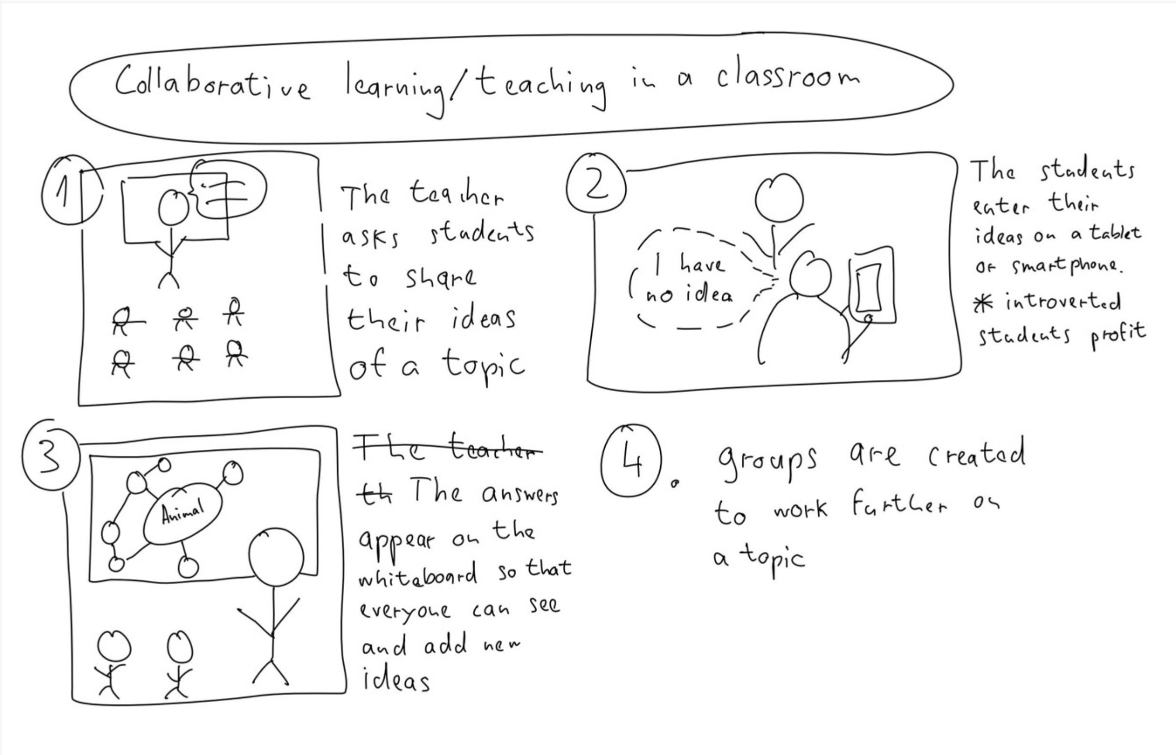
The other two participants suggested concept-map-based quizzes or skeleton concept maps as exercises to prepare for summative assessments (Fig. 17). However, they suggested that these concept maps might also be helpful for the summative assessment itself, mainly because they add a motivating, playful element to the assessment.

Fig. 17*: Example skeleton concept map suggested by student 2 (focus group 1)*



The students from the university stressed the importance of being actively involved in concept mapping. Their stories centered around the idea of combining instruction in a classroom with active, concept map-based learning approaches. Student 1 imagined using concept maps for brainstorming to collect existing knowledge about a new topic. Student 3 stressed the purpose of brainstorming via concept mapping but as an instructor-initiated, individual “fill-in-the-blanks” activity to spark creativity before writing a story. Students would fill blanks in a concept map to collect relevant terms for their stories and then use all terms in their writing (focus group 2: “And then he can invent a story with all of these words. This is creativity, he has to think about it a lot, and in his story there are words afterwards which he had not imagined directly"). Student 2, finally, presented a story where students first collect ideas about a topic on their smartphones or tablets. Afterward, the ideas could be automatically collected and visualized as a concept map on a presentation screen. This collective concept map could then be the foundation for following educational activities (Fig. 18).

***Fig. 18**: Collaborative learning in the classroom as suggested by student 2 (focus group 2)*



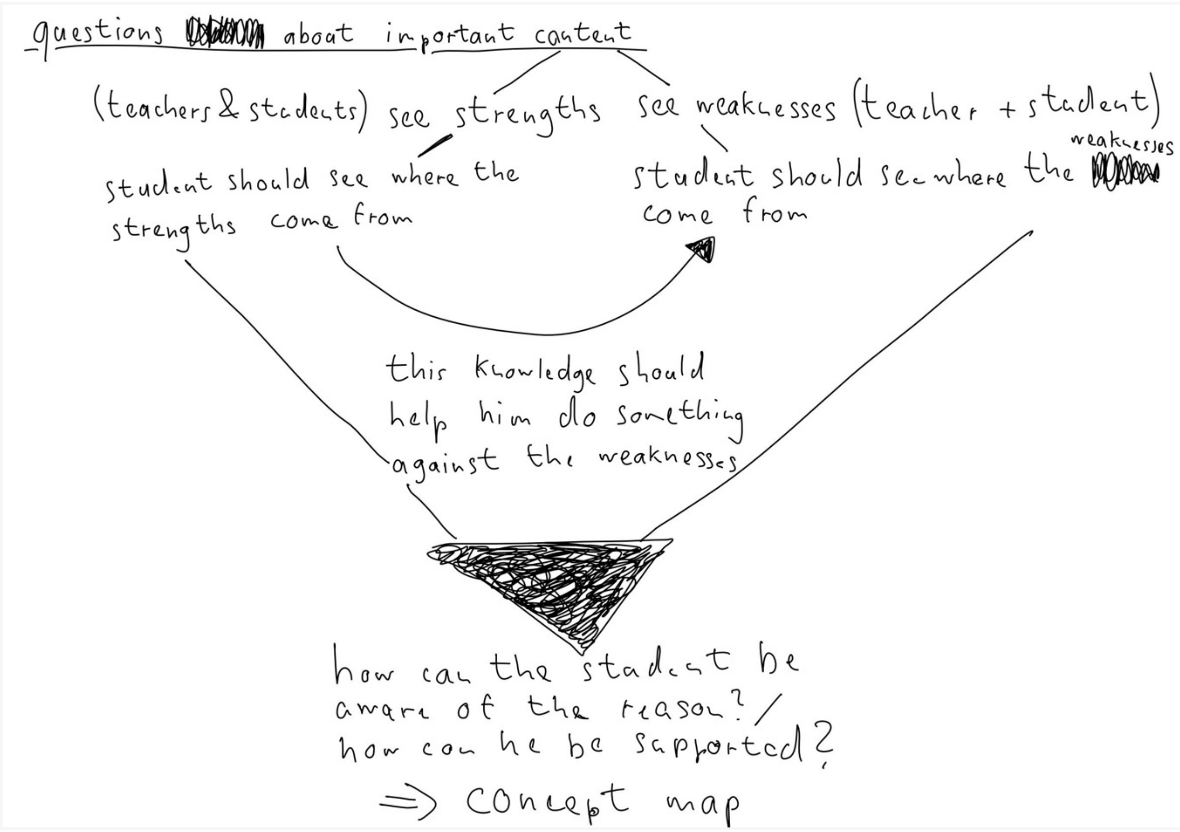
The instructors in focus group 3 discussed using concept mapping for instructional and assessment purposes. Three of their stories addressed using concept maps as instructional materials, such as illustrating grammatical adaptations of French verbs (instructor 2, see Fig. 22) or visualizing complex relationships in geography (instructor 4). In the following discussions, instructors shared that some students start integrating concept mapping in their learning activities, independent of instruction.

The remaining two stories created by instructors explored formative assessment (Fig. 19). Instructors discussed that such formative assessment is important but often not sufficiently addressed (instructor 5, focus group 3: "I have selected formative learning because we often miss out on it in learning."). The related stories describe concept mapping activities for individualized feedback to prepare for summative assessment:

> I could imagine that the instructor presents the topics of a test and plans 1-2 hours of active learning during regular classes. Learners could individually or, depending on the complexity of the topic, collaboratively create a concept map of the topics they have to learn for the test. […] And then, we look at what the individual learners or groups have discovered, and this allows the instructor to give feedback by saying: But this connection, you did not see this relation well,

how do the others see it? And only after this feedback, there is a summative test. (instructor 5, focus group 3)

Fig. 19*: Integration of concept maps in formative assessment as suggested by instructor 1 (focus group 3)*



Furthermore, instructors reflected on changes to their role, which is assumed to shift towards being a learning coach (Reigeluth et al., 2017). Stories by instructors envision using concept maps at the start of a new topic to extract what students already know about the topic (instructor 3, focus group 3: "I think it is very important that we pick students up where they are at the moment. This means that, in a first assessment about any topic, you need first to discover their current knowledge."). These concept maps could then serve as the basis for defining and constantly adapting learning goals for a lesson, for example, when "maybe I do not reach my primary goal and have to go back to the current state, […] and maybe I need another goal first and have to sharpen my vision" (instructor 3, focus group 3).

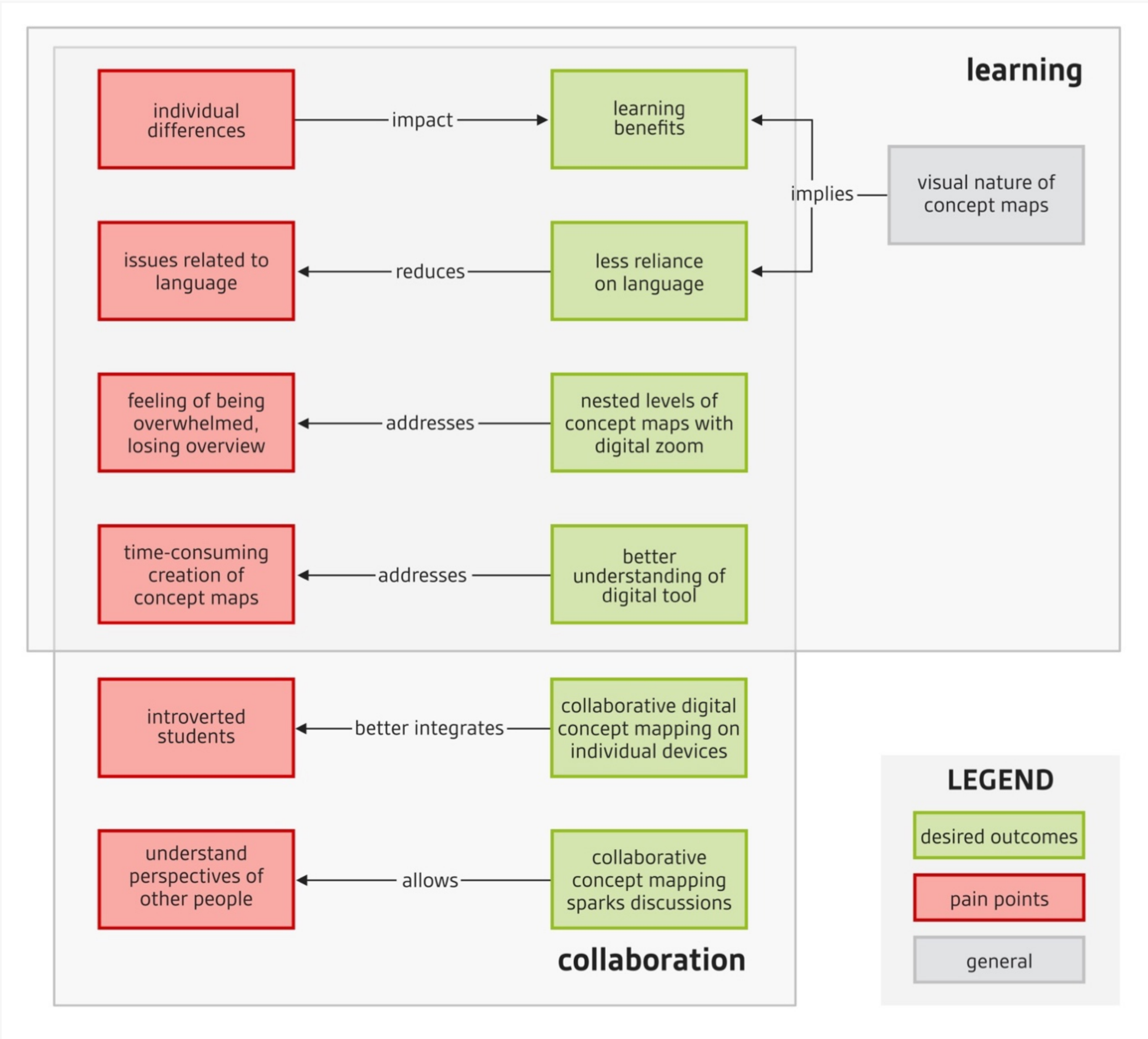
3.5.2 RQ 2: Desired Outcomes and Pain Points

Fig. 20 and 23 show the desired outcomes and pain points classified by scenario. Transparent overlays reflect where desired outcomes and pain points apply to different scenarios.

3.5.2.1 Desired Outcomes and Paint Points for Learning

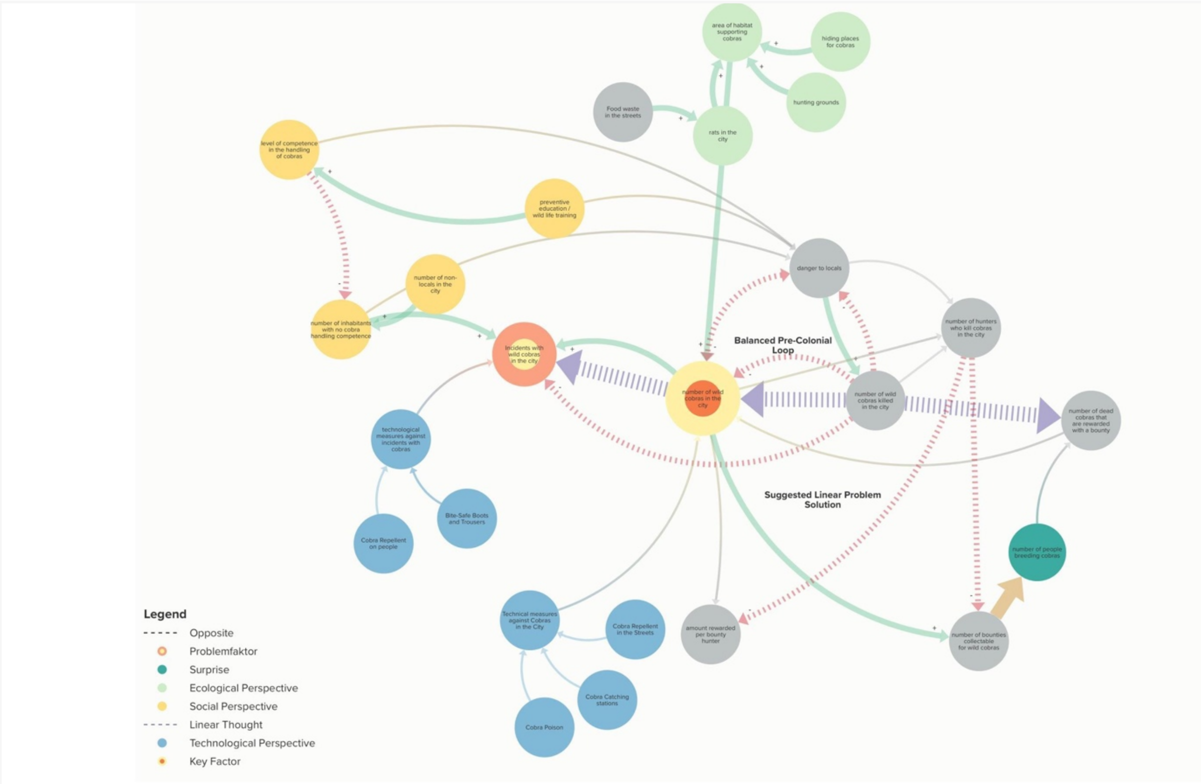
For individual and collaborative learning (see Fig. 20), participants expressed that the visual nature of concept maps could have two benefits. First, they suggested that it might facilitate learning (student 2, focus group 2: "I have always extracted this information by myself, and […] it is more likely that I remember this. I have such a picture to think about."). Digital concept mapping tools can facilitate such a clear, ordered, and structured overview of a topic. However, participants suggested that some, but not all, learners might benefit from visualizing information with concept maps (student 2, focus group 2: "Well, I am giving private lessons, and I have tried it [visualizing information] once with one person, and it did not work. […] And with his sister, it worked very well. And I think it depends a lot on the person.").

Fig. 20: *Major desired outcomes and pain points covering learning and collaboration*



Second, participants suggested that the visual nature of concept maps could help to address language-related issues. For example, students from schools expressed difficulties switching languages between subjects and suggested that a concept map could include translations of terms. Furthermore, participants discussed how a digital concept mapping tool could address general pain points with concept maps. For example, participants felt confused and overwhelmed by some of the complex examples (e.g., Fig. 21). They suggested that a digital concept mapping tool could include several sub-concept-maps and continuously adjust what is visible depending on the zoom level.

***Fig. 21**: Causal diagram example that felt overwhelming for some participants*



References: Raber, Bo, *https://kumu.io/boraber1990/cobra#the-cobra-effect*

Another pain point is that creating concept maps is experienced as time-consuming and cumbersome, for example, when a concept mapping tool is too complex. Some participants emphasized the simplicity of paper-based concept mapping but also valued digital capabilities like easily rearranging elements. These findings emphasize that participants expect an intuitive, easy-to-use interaction design and digital capabilities for concept mapping tools.

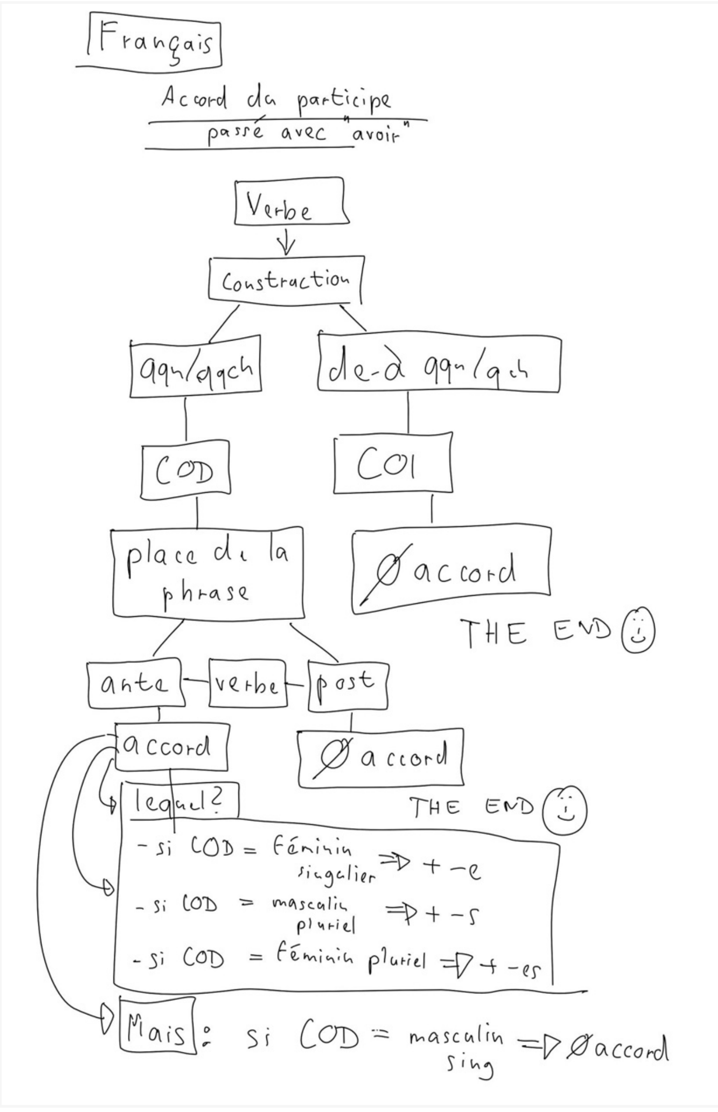
3.5.2.2 Desired Outcomes and Pain Points for Collaboration

Regarding collaborative learning (see Fig. 20), participants expressed a strong wish to understand the perspectives of others, for example, in collaborative problem-solving. Focus group 1 had used collaborative concept mapping in a school project and reported that it sparked meaningful discussions about their ideas. Instructors agreed on the value of these discussions for understanding complex relationships in learning. Furthermore, students emphasized that concept mapping might better include introverted students in the classroom. For example, when students create and present individual concept maps as a basis for a collaborative concept map, "they would then also have the possibility to present their ideas without having to stand up or speak up" (student 2, focus group 2).

3.5.2.3 Desired Outcomes and Pain Points for Teaching and Instruction

For teaching and instruction (see Fig. 23), some participants suggested using concept maps as instructional materials to help learners understand a topic better. Participants expressed the desired outcomes that concept maps might be particularly well suited for summarizing topics because they allow making the relations explicit (student 3, focus group 2: "I write a summary for myself. But then you do not have these relations. […] And I think this aspect of putting things in relation, this helps me […]"). Other participants suggested that instructors create concept maps, for example, for complicated processes in grammar (Fig. 22). Students could use the outlined process to choose the correct grammatical ending in French.

***Fig. 22**: Concept map as instructional materials explaining a French grammar topic as suggested by instructor 2 (focus group 3)*



Active concept mapping, especially in classrooms, was frequently suggested in participants' stories (see Table 5), often associated with desired outcomes for meaningful, long-term learning and pain points regarding motivation. For example, instructor 3 (focus group 3) expressed that meaningful learning requires a high motivation of students:

> What could also be interesting is this meaningful learning. Students often have problems to motivate themselves for something when they do not see a value in it. They have to, I think, the first task is to teach them the value of something. Teach them is hard or maybe formulated wrongly, but to see the value of something, em and then you address the problem with another motivation.

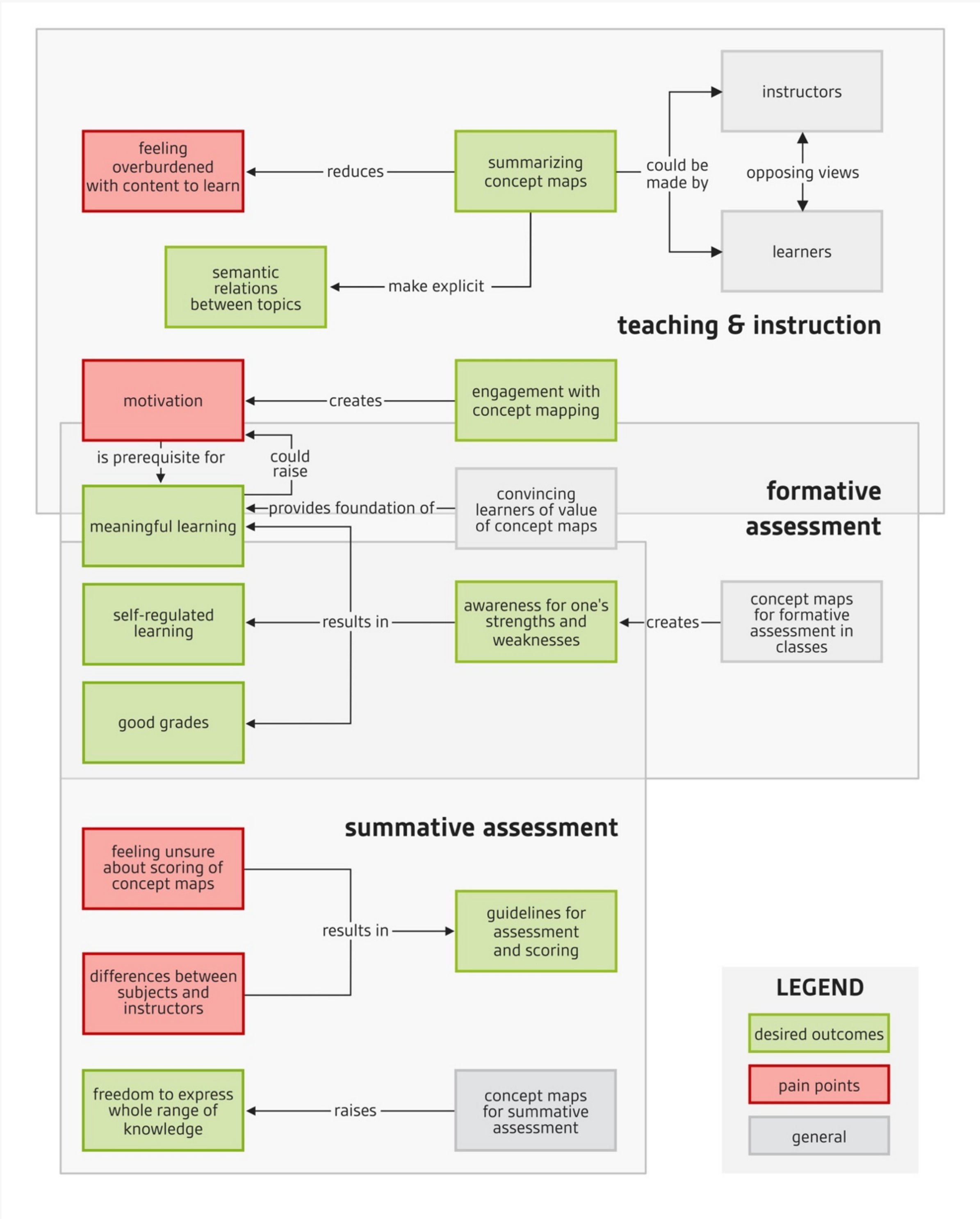
Several of the stories by participants expressed the hope that concept mapping might enhance motivation to learn, in particular by being engaging or playful. These stories often connected teaching scenarios with other scenarios, for example, collaborative learning and formative assessment, and thus emphasize an educational shift from teaching to active learning (Reigeluth et al., 2017).

3.5.2.4 Desired Outcomes and Pain Points for Assessment

Regarding formative and summative assessment (Fig. 23), the student participants often connected formative assessment to a pragmatic, instrumental goal: better preparation and, as a consequence, higher chances for a better grade in summative assessment. Both student and instructor focus groups suggested formative concept mapping during classes as "active preparation of the assessment" (instructor 5, focus group 3) that could help students "learn better and in particular more sustainably for an assessment" (instructor 5, focus group 3). However, instructors went beyond this preparatory aspect of formative assessment and expressed desired outcomes that it might help students see their strengths and weaknesses. Their discussion emphasized self-regulated learning, with the instructor taking up the role of facilitator or coach of learning (focus group 3, instructor 1):

> It is about supporting the student to learn more effectively. This means I would also have a similar situation to a classroom test to discover which important content a student knows and which he does not know, so that he becomes aware of where are his strengths, where are weaknesses. It would be ideal if the student himself would discover where these strengths come from, where these weaknesses come from, and if he could apply the reasons for the strengths to the weaknesses.

Fig. 23: Desired outcomes and pain points about teaching & instruction and assessment



With regard to summative assessment, students were frustrated by not being able to express their complete knowledge in a test. They suggested that a concept map could answer a question more completely because “most often students know more than the teacher is asking, and with a concept map, […] then the student could write everything he knows” (student 2, focus group 1). Furthermore, a concept map template could clearly define what an instructor expects of an answer, for example, by providing the appropriate number of blanks to be filled.

However, two major points of discussion appeared in the focus groups. The first point of discussion referred to how to score concept maps in summative assessment. Students discussed whether an open, concept map-based assessment would be harder or easier for instructors to score than traditional tests (focus group 1). The second point of discussion referred to the need to agree on using concept maps across different subjects (instructor 4, focus group 3: “if you base your evaluation to a good part on this, […] then it has to be clear that you are not the only one who is doing these things”). For example, instructor 4 expressed accepting a concept map as an answer, but the discussion made clear that not all instructors agree. In summary, participants agreed that concept maps are valuable tools for assessment, in particular formative assessment. However, questions remained regarding the scoring of concept maps and their use across different subjects.

3.6 Discussion

The present study contributes to understanding which aspects of digital concept mapping are particularly important to learners and instructors. The results support earlier research on the advantages of concept mapping, for example, being able to structure knowledge meaningfully (Shavelson et al., 2005), fostering social interaction and understanding the perspectives of others (Basque & Lavoie, 2006), or reducing the need of relying on language skills via concept mapping (Nesbit & Adesope, 2013). The present section will discuss four contributions regarding digital concept mapping and three contributions regarding the methodological approach of storytelling.

3.6.1 Contributions to Digital Concept Mapping

First, results revealed interest in using concept maps for assessment purposes, especially in formative assessment. Interestingly, the students in focus group 1 did not suggest individual feedback by the instructor during formative assessment but were mainly interested in more efficient learning and better grades in summative assessment. Students expressed that instructors typically do not include formative assessment activities in their classrooms. Instead, students organize these formative activities themselves as part of their learning for a summative assessment (focus group 1). Instructors agreed that formative assessment should be included more frequently and expressed interest in helping their students discover their strengths and weaknesses. Formative assessment with concept maps could address several pain points expressed by the participants: It could help the learners see their strengths and weaknesses, provide them with helpful feedback, make learning more efficient, and finally result in better grades in summative assessment. This argumentation could help instructors to convince students of the values of concept mapping and thus contribute to establishing concept mapping in the educational system[11].

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[11] I have picked up several of these ideas in instructional materials that I developed in collaboration with SCRIPT as part of the applied contributions of the dissertation.

Second, regardless of whether concept mapping is used for formative or summative assessment, instructors will need the competence to analyze or "read" concept maps to draw meaningful conclusions. The study revealed insecurity about how to do such an analysis of concept maps, in particular with regard to systematic scoring of concept maps. Thus, identifying appropriate scoring methods of concept maps and providing relevant guidelines for instructors is a vital part of a human-centered digital concept mapping project. Chapter 10 addresses this task with the help of a systematic literature review of concept map scoring.

Third, participants identified opportunities for digital concept mapping, for example, nesting concept maps and using the zoom level to reveal details or connecting elements in concept maps to additional information. However, participants also expressed challenges with regard to digital concept mapping, for example, the need to learn how to operate a user interface. These results suggest a need for a human-centered design approach for digital concept mapping: Digital tools offer a range of advantages, but these do not come automatically. Instead, the user interface and interaction design should be thoroughly investigated to avoid adding extraneous cognitive load of how to operate the interface (Hollender et al., 2010). Participants also expressed the hope that a digital concept mapping tool might engage and motivate learners, potentially relating to the hedonic dimension of user experience (Diefenbach et al., 2014a). Part III addresses these concerns by systematically investigating the user experience design of a digital concept mapping tool.

Fourth, the stories covered the full range of potential scenarios identified for concept mapping. They also covered different knowledge domains and ranged from specific purposes (e.g., learn about world war in history) to very general competencies (e.g., building competencies to self-regulate learning and understand complexity). The results indicate the need for educational guidelines (outlining how to use digital concept mapping in a wide range of educational settings) and a general-purpose digital concept mapping tool that is easy and flexible to use.

3.6.2 Methodological Contributions

Beyond the contributions regarding digital concept mapping, my study has a range of methodological contributions. First, the use of storytelling successfully allowed participants to think about and share their ideas. All scenarios were covered in the stories, and furthermore, the discussions frequently addressed aspects that crossed the boundaries of scenarios, for example, by generalizing desired outcomes and pain points that apply to different scenarios. However, stories also were close to the lives of the participants. For example, the younger students in focus group 1 concentrated on preparing for summative assessments, and thus, imagined concept maps to enhance their preparation for a test. The older students in focus group 2 concentrated on integrating concept mapping meaningfully in classroom teaching to help learners acquire competencies like, for example, creativity or collaboration. The instructors in focus group 3 finally concentrated on addressing what they perceived as shortcomings in education, especially in terms of formative assessment and helping learners address a problem (e.g., French grammar). These observations emphasize the need to carefully include participants from all involved groups in the sample to cover their perspectives.

Second, my results demonstrate the value of having participants present and discuss their stories. These discussions frequently went beyond the original story idea and addressed related areas. In particular, the discussions successfully revealed the deeper desired outcomes and pain points behind the envisioned stories. Potentially, it might also be an option to create heterogeneous focus groups, including students and instructors in the same focus group. However, such a setting should be thoroughly pre-tested to avoid the differences in roles impacting the openness of the following discussions, for example, because younger students feel discouraged discussing their ideas with older participants.

Third, the stories showed a selection of different forms for storytelling, for example, texts in bullet points, example concept maps, storyboards, and abstract flow charts of processes. I suggest that the choice of templates and scenarios for the storytelling should reflect this freedom of form. My template originally included lines to facilitate writing, but these lines were removed after pre-testing revealed that they might lead participants into writing a story (instead of picking another form). Thus, I suggest that UX researchers and designers should be careful when creating storytelling templates and avoid guiding their participants into a specific form of stories. My results indicate that it is preferable to allow participants to choose the form of story that best suits their needs.

3.6.3 Limitations

In the present study, I took the role of the focus group moderator by asking each participant to share feedback and opinions about the stories. However, an alternative might be to include an additional creative secretary whose role is to deepen the discussions while the moderator documents the storytelling (Kankainen et al., 2012). I did not include such a creative secretary in the present study but used templates instead to document and explain the stories. Although my results make me confident about the quality of the data, in particular regarding discovering deeper desired outcomes and pain points behind the stories, I suggest that future co-creative storytelling focus groups could explore whether such a creative secretary might enhance data quality even further.

3.7 Conclusion

The present chapter explored a combination of co-creative storytelling and focus group discussions to empower participants to communicate their vision of integrating a digital concept mapping tool in their educational activities. Three focus groups were performed with students and instructors. Results indicated a substantial need for using concept mapping for instructional purposes, individual and collaborative learning, and formative and summative assessment. The discussion of the stories shed light on the desired outcomes and pain points that drive the described experiences. The study outlined important considerations for the design of a digital concept mapping tool, for example, flexibility to account for various scenarios, an intuitive user interface, and a motivating design.

4 All You Need is…: Exploring Psychological Needs to Design for Positive Experiences

Abstract

Experience design aims at shaping positive human experiences with technology. However, such design requires a solid understanding of what defines these experiences. Psychological needs profoundly impact experiences and are, thus, a solid foundation for designing positive experiences. The present study aims at identifying the importance and role of psychological needs in digital concept mapping. Based on 17 qualitative interviews, it addresses four research questions: Which experiences do participants have with concept mapping and other visualization methods? Which psychological needs do participants consider important in digital concept mapping? What are the reasons for these psychological needs? And how would an ideal digital concept mapping tool look to fulfill these needs? The study found that concept mapping could fill the gap for a knowledge visualization method focusing on structural relations and contributed to a psychological needs profile for digital concept mapping, mainly based on pleasure and stimulation, competence and effectiveness, and security and control. Furthermore, the study identified hypotheses for design recommendations of a digital concept mapping tool. Finally, it created a structured set of design ideas to fulfill the identified psychological needs in digital concept mapping tools.

4.1 Introduction

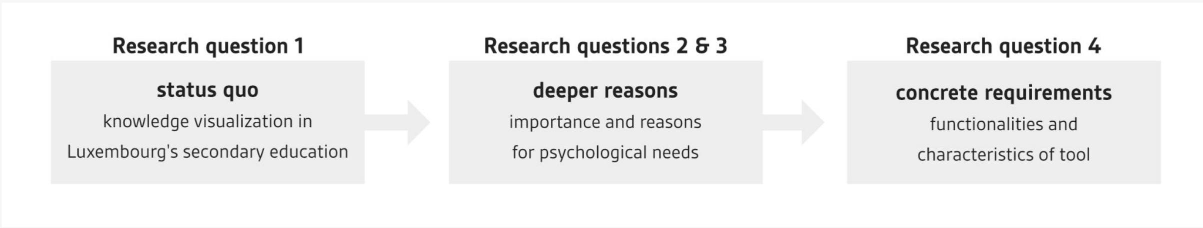
With the rising recognition of user experience (UX), design is increasingly taking over a perspective of experience design (Hassenzahl, 2010). Such an experience design is deeply human-centered and attempts to shape human experiences with technology. A fundamental step of experience design is first to understand experiences to identify what to design for specifically. In the context of the current research project, these experiences relate to concept mapping to visualize and assess knowledge. Visualizations are "cognitive tools aiming at supporting the cognitive system of the user" (Keller & Tergan, 2005, p. 5), usually with a combination of textual and visual modes. However, a substantial variety of knowledge visualization methods exist, for example, concept maps, mind maps, diagrams, and argument maps (Eppler, 2006; Davies, 2011)[12]. All of these have their specific characteristics, serve particular purposes, and might therefore create different experiences. Thus, identifying what characterizes these experiences is a critical first step for experience design.

Fig. 24 outlines the purpose of the present chapter. First, it aims to identify the status quo of experiences with knowledge visualization in Luxembourgish secondary education: which methods are known, and what are their uses? Afterward, it aims to identify the deeper reasons that shape these experiences. In

[12] Definitions and examples of different visualization methods are available in Chapter 1.

the present study, I will argue that psychological needs provide a solid foundation for investigating these deeper reasons. Finally, the chapter aims to identify concrete requirements for a digital concept mapping tool. As outlined in Chapter 1, the study is part of a larger research project with a fundamentally human-centered design approach. Thus, the aim is to involve human participants in the research and design process by sharing their perspectives.

***Fig. 24**: Aims of the present study*



4.2 Psychological Needs as Drivers of Experience

Psychological needs are "innate psychological nutriments that are essential for ongoing psychological growth, integrity, and well-being" (Deci & Ryan, 2000, p. 229) and are vital foundations for providing a positive user experience (Hassenzahl et al., 2010; Hassenzahl, 2003). Psychological needs also play an important role in learning and assessment (Evans et al., 2012; Katartzi & Vlachopoulos, 2011; Oostdam et al., 2018), for example, by promoting positive emotions that have been found to impact performance in assessment situations (Desmet & Fokkinga, 2020; Masters et al., 1979; Tien et al., 2018; Yang et al., 2013). The present study explores the role of psychological needs in digital concept mapping. In the following section, I will address three key questions to argue why these needs are important: What is the benefit of focusing on psychological needs for designing a digital concept mapping tool? Which psychological needs should be considered? And how can psychological needs be meaningfully discussed with participants to inform design?

4.2.1 Benefit of Psychological Needs for Possibility-driven Design

Beyond the importance of psychological needs fulfillment for human well-being (Tay & Diener, 2011), focusing on needs can shift design from solving problems to enabling possibilities (Desmet & Hassenzahl, 2012). Human-centered design often focuses on solving problems (Ney & Meinel, 2019). In this view, the purpose of design is to remove a mismatch between a current state and an ideal state (typically with regard to instrumental "do-goals"), for example, by making a product easier to use (Desmet & Hassenzahl, 2012; Hassenzahl, 2010). Such problem-driven approaches were highly successful in creating products but have also been described as a "disease model of human technology use" (Hassenzahl, 2010, p. 28). This view is in line with the traditional focus on usability: it attempts to create satisfaction by identifying and solving problems of technology use (Hassenzahl, 2010).

As an alternative to this problem-driven design approach, Desmet and Hassenzahl (2012) propose a possibility-driven design approach. Its purpose is to create positive experiences instead of avoiding negative ones. Instead of focusing on satisfaction, possibility-driven design focuses on designing for happiness (Desmet & Hassenzahl, 2012). Two paths to happiness have been proposed: hedonia and eudaimonia. *Hedonia* refers to a pleasurable and comfortable life (Huta & Ryan, 2010). *Eudaimonia* refers to a "good life" and meaningful goals (Desmet & Hassenzahl, 2012; Huta & Ryan, 2010; Mekler & Hornbæk, 2016). User experience has traditionally focused on the hedonic dimension (as opposed to the pragmatic dimension; Diefenbach et al., 2014a), but the eudaimonic dimension of user experience is increasingly being discussed as a distinct perspective (Hammer et al., 2018; Mekler & Hornbæk, 2016). However, hedonia and eudaimonia are not clear-cut distinctions, in particular because a "good life is also a pleasurable life" (Desmet & Hassenzahl, 2012, p. 10): meaningful experiences are themselves sources of pleasurable experiences.

Possibility-driven design suggests exploring possibilities of designing for pleasure and meaningfulness instead of concentrating on fixing problems (Desmet & Hassenzahl, 2012). In line with this argumentation, the purpose of the present study is to explore how a digital concept mapping tool could contribute to well-being in education. It investigates which deeper psychological needs instructors and learners want to fulfill in digital concept mapping and the reasons for these psychological needs. To the best of my knowledge, no prior study has investigated the role of psychological needs to motivate the design of a digital concept mapping tool. However, it is first necessary to define which psychological needs should be considered in the data collection.

4.2.2 Theories of Psychological Needs

Different theories of psychological needs exist (Sheldon et al., 2001). Two particularly well-known examples are the theory of human motivation by Maslow (1943) and Self-Determination Theory by Ryan and Deci (2002). The theory of human motivation (Maslow, 1943) argues that psychological needs are the main drivers of human actions. One of its fundamental ideas was to suggest that different kinds of psychological needs exist in a particular hierarchical ordering: physiological needs (such as hunger), safety, love, esteem, and self-actualization. Maslow (1943) suggested that humans will first attempt to fulfill the needs lower in the hierarchy before they turn to the needs higher in the hierarchy. In subsequent years, the idea of a generally valid, hierarchical ordering of psychological needs has been converted into a well-known model of a "pyramid" by others (Bridgman et al., 2019). Although the pyramid model remains popular today (Bridgman et al., 2019), subsequent research found that humans do not necessarily strive to fulfill psychological needs in the suggested order (Desmet & Fokkinga, 2020). However, other suggestions by Maslow (1943) were found to be accurate, in particular the ideas of viewing human needs as universal drivers of motivation (Desmet & Fokkinga, 2020; Tay & Diener, 2011).

Self-Determination Theory (SDT; Ryan & Deci, 2002) posits three basic needs: competence, relatedness, and autonomy. Competence refers to the need for effective interactions with one's environment and to express one's competencies (Oostdam et al., 2018; Ryan & Deci, 2002). Relatedness refers to the need to have close social relations and a sense of belongingness (Ryan & Deci, 2002). Autonomy refers to the need to control one's behavior (Ryan & Deci, 2002). These needs have been closely linked to intrinsic motivation (Schultheiss et al., 2012) and validated in different settings, for example, maladaptive behavior in schools (Oostdam et al., 2018).

The present study builds on work by Sheldon et al. (2001). In an attempt to integrate different theories of psychological needs, Sheldon et al. (2001) identified and validated a list of ten basic psychological needs: self-esteem, autonomy, competence, relatedness, pleasure/stimulation, physical thriving, self-actualizing/meaning, security, popularity/influence, and money/luxury (Sheldon et al., 2001). Their work has been successfully adapted to evaluate need fulfillment and user experience with digital products and services (Lallemand & Koenig, 2017). However, the current study was interested in inspiring meaningful discussions with participants concerning the importance and reasons of psychological needs for digital concept mapping. Thus, a questionnaire to evaluate need fulfillment is not the correct approach for this study. The following section will argue that a card-based exploration of psychological needs is more appropriate in the present context.

4.2.3 Card-based Exploration of Psychological Needs

Cards of various kinds are increasingly used in human-computer interaction (HCI). In this paper, I am concerned with "cards used to assist or provide structure to the design process" (Wölfel & Merritt, 2013, p. 479), not with other methods like card sorting (Rosenfeld et al., 2015). Card-based methods are used in different stages of the UX design process. For example, they are an adequate method for the exploration phase of UX design to identify what is important to humans regarding the topic of the card (Diefenbach et al., 2014b). Card-based methods can spark creativity (Bleuzé et al., 2014) and are, thus, often used in the ideation phase of UX design. Cards are also used for training purposes (Lallemand, 2015). Finally, cards can serve as templates for evaluating products (Diefenbach et al., 2014b).

Card-based methods cover a range of topics in HCI, such as playful experiences (Lucero & Arrasvuori, 2010) or emotional granularity (Yoong et al., 2013). Cards are also a frequent method for exploring psychological needs. The UX cards (Lallemand, 2015) and the "Bedürfniskarten" (Diefenbach et al., 2014b) are both based on a selection of the basic needs identified by Sheldon et al. (2001). The present study is based on the UX cards (Lallemand, 2015) because these were available in French and English. As a native speaker of German, I created a German translation. The "Bedürfniskarten" are similar but only available in German and English. Thus, given Luxembourg's multilingual situation, creating a French version would have been necessary but harder to accomplish. Furthermore, the UX cards include negative images representing the lack of fulfillment of a particular need. These could inspire participants to consider experiences that do not satisfy a particular need. Such a perspective is highly relevant because a product could harm need fulfillment (Desmet & Fokkinga, 2020), and design has to address this concern. Other relevant card sets exist that move beyond the suggestions of basic needs by Sheldon et al. (2001), such as the inspiration cards based on 13 psychological needs by Desmet and

Fokkinga (2020) or the 77 human needs system by DE3P (https://www.de3p.com). However, although these sets are very interesting and might reveal additional insights due to the larger selection of covered psychological needs, they were not publicly available at the time of the present study (2018).

The present study used the UX cards (Lallemand, 2015) to inspire a meaningful exchange about psychological needs in digital concept mapping (Diefenbach et al., 2014b). The UX cards are based on seven of the basic needs that are the most prominent regarding digital products (Lallemand, 2015; Sheldon et al., 2001). Each card contains a headline with two images on the front side (covering positive need fulfillment and negative absence of need fulfillment) as well as a short description, a list of typical examples, and keywords on the backside (Fig. 25). In total, seven psychological needs are covered (Table 6). The aim of the present study was to identify which psychological needs are particularly important for digital concept mapping[13], thus providing design directions to create positive experiences. The findings contribute to the creation of a "product-specific needs profile" (Desmet & Fokkinga, 2020, p. 11) for concept mapping.

***Fig. 25**: Example of a UX card derived from Lallemand (2015)*

[13] My goal is not to identify a universal importance of needs. Evidence suggests that needs are universal and rather equally important for well-being (Hassenzahl, 2010; Sheldon et al., 2001). However, I am interested in how concept mapping mapping can contribute to fulfillment (or deprivation) of needs (Hassenzahl, 2010), and identify which needs are particularly vital in this regard.

***Table 6**: Psychological needs and definitions used in the present study (Sheldon et al., 2001, p. 339; Lallemand, 2015)*

Need	Definition
Autonomy and independence	“Feeling like you are the cause of your own actions rather than feeling that external forces or pressures are the cause of your actions”.
Competence and effectiveness	“Feeling very capable and effective in your actions rather than feeling incompetent or ineffective”.
Relatedness and belongingness	“Feeling that you have regular intimate contact with people who care about you rather than feeling lonely and uncared for.”
Pleasure and stimulation	“Feeling that you get plenty of enjoyment and pleasure rather than feeling bored and understimulated by life.”
Security and control	“Feeling safe and in control of your life rather than feeling uncertain and threatened by your circumstances.”
Popularity and influence	“Feeling that you are liked, respected, and have influence over others rather than feeling like a person whose advice and opinions nobody is interested in.”
Self-actualization and meaning	“Feeling that you are developing your best potentials and making life meaningful rather than feeling stagnant and that life does not have much meaning.”

4.3 Research Questions

The present research aims to contribute to the experience design of a digital concept mapping tool. In particular, it addresses the following research questions:

- *Research question (RQ) 1*: Which experiences do participants have with knowledge visualization methods?
- *Research question (RQ) 2*: Which deeper psychological needs do participants consider the most important to fulfill regarding digital concept mapping?
- *Research question (RQ) 3*: Which reasons do participants give for selecting psychological needs regarding digital concept mapping?
- *Research question (RQ) 4*: How would, as a consequence, an ideal digital concept mapping tool look like for the participants?

RQ 1 aims at defining current experiences with knowledge visualization to identify the role that concept mapping could play in Luxembourgish secondary education. RQ 2 aims at identifying which psychological needs are particularly important for digital concept mapping. RQ 3 aims at discovering the reasons for choosing these particular psychological needs. RQs 2 and 3 together contribute to creating a needs profile for digital concept mapping as suggested by Desmet and Fokkinga (2020). Finally, RQ 4 aims at identifying which aspects are particularly important to participants regarding the concrete concept mapping tool itself. These aspects are expected to provide the foundation for further design. RQ 4 is similar to the “ideal concept mapping tool” activity in the co-design study in classrooms (see Chapter 2) but has a stronger focus on revealing how the identified psychological needs manifest in characteristics or functionalities of the digital concept mapping tool.

4.4 Methodology

The present study is based on 17 interviews of approximately 60 minutes each:

- eight instructors (five involved in classroom teaching, two involved in consulting instructors and organizing courses targeted at instructors),
- five students (two from schools, three from university)
- four project stakeholders (three researchers and one instructor involved in the organization of the School Futures project)

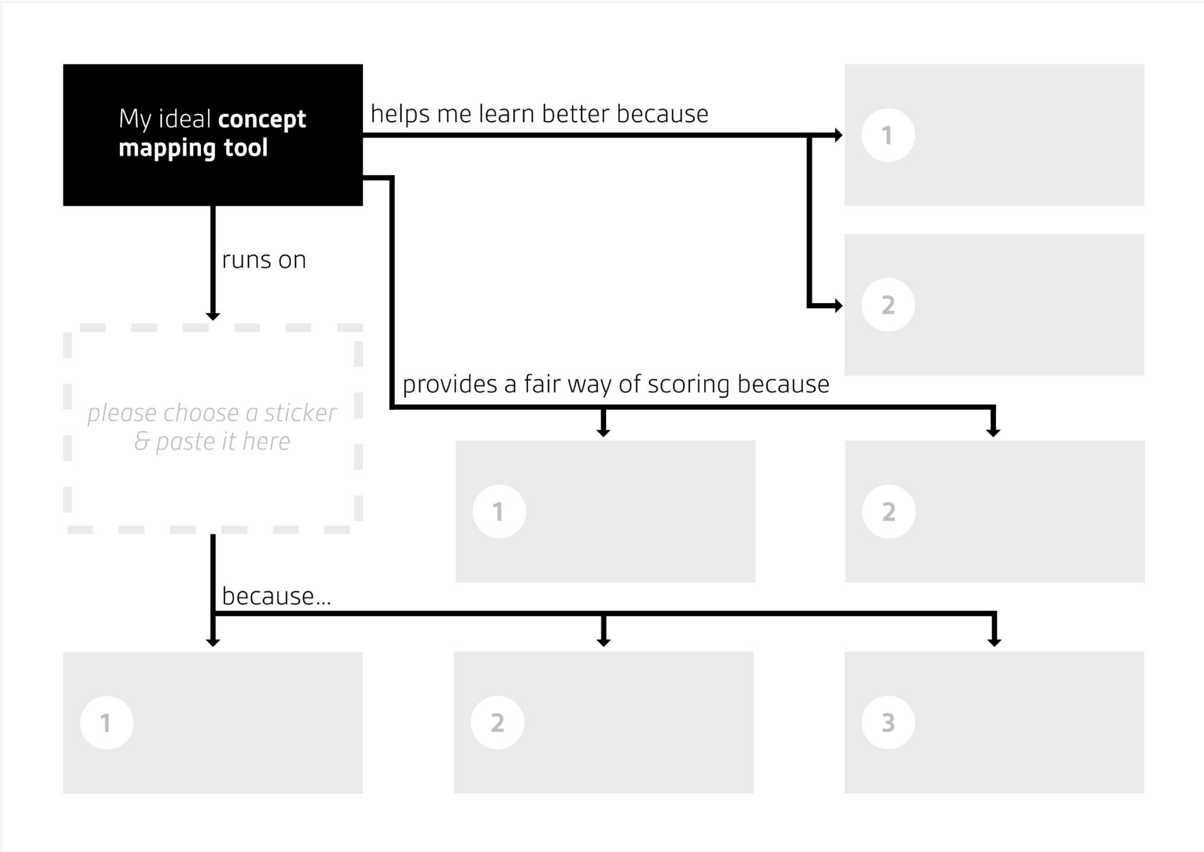
At the beginning of the session, I outlined the purpose of the study and answered questions. Afterward, the participants signed the informed consent form. In case of minors, additional informed consent was collected from their parents before the session. After the informed consent, I introduced participants to the method of concept mapping and provided examples (see Appendix A). Participants were free to answer in Luxembourgish, French, German, or English. All materials (presentation, consent forms, templates, and UX cards) were available in French, German, and English[14]. Data collection had three parts:

1. The participants shared their experiences with methods of visualizing knowledge in a semi-guided interview. I asked questions about which visualization methods the participants know and in which contexts they have used these methods. I also asked follow-up questions to engage participants in elaborating on what they said, for example, when they referred to difficulties they encountered.
2. I provided participants with the UX cards (Lallemand, 2015). I introduced participants to the cards by pointing them to the negative and positive aspects on the front side and the definitions and examples on the backside. Then, I laid each UX card in front of the participants and read the definition from the back of the card out. Afterward, I asked participants to order the UX cards according to their importance for concept mapping. Participants were free to choose as many cards as they liked and could refer to the definition and examples on the backside at any time. When participants indicated they had finished the ordering, I asked them to elaborate on the reasons for their choices. I also asked follow-up questions to understand the statements of participants fully.
3. I provided participants with a template to outline their ideal concept mapping tool (Fig. 26). The template was identical to the one used in the co-design study in the classrooms (see Chapter

[14] I discussed translations into Luxembourgish with a native speaker but decided to use the German or French versions, like other written materials used in Luxembourgish education.

2). However, I asked participants to elaborate on the reasons for their answers in the template. Most participants preferred explaining their ideas for an ideal concept mapping tool to filling the template.

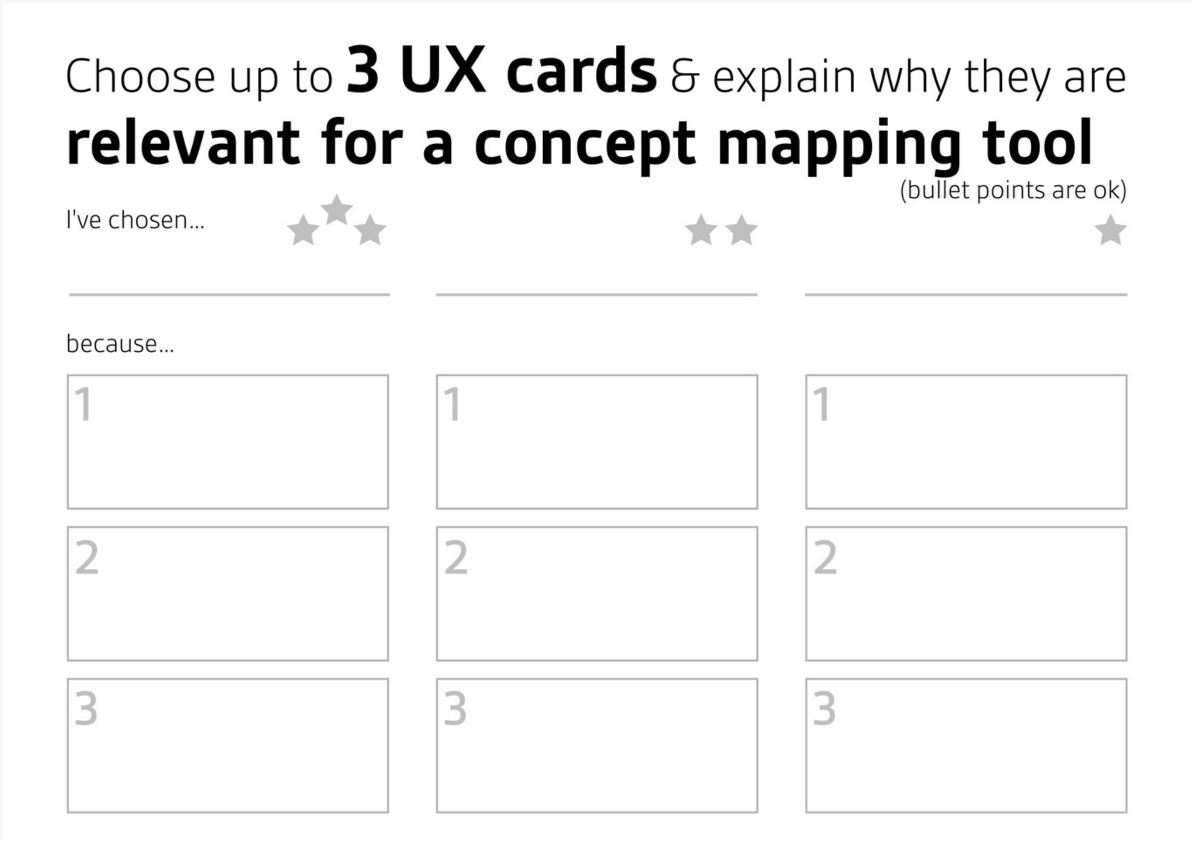
Fig. 26: *Template for an ideal concept mapping tool*



4.4.1 Pre-testing

All materials and the data collection were pre-tested with a group of HCI researchers. I provided the participants with a template to select the three most important psychological needs regarding digital concept mapping (Fig. 27). The template also included text areas for explaining the reasons behind the choice. The pre-test originally included additional activities (see Chapter 3) but revealed that participants preferred focusing on a smaller number of activities. Thus, I decided to split the data collection methods into different parts of the study. Furthermore, the oral discussions about the role of individual psychological needs proved to be highly revealing. Therefore, I decided to transcribe the oral discussion rather than using the template.

Fig. 27: *Template for the UX cards activity (discarded after pre-testing)*



4.4.2 Analysis

The interviews were audio-recorded. I imported the recordings into MaxQDA for transcribing and performed a qualitative summarizing content analysis (Mayring, 2002). First, I paraphrased each statement into a code. I combined codes when their semantic meaning was identical. Second, I categorized codes into used visualization methods and tools, psychological needs, and functionalities and characteristics of a digital concept mapping tool. Third, I analyzed the codes to answer my research questions. Regarding RQs 1, 3, and 4, I wrote the codes on post-its and created an affinity diagram (Holtzblatt et al., 2005) specifying their relations (Fig. 28). Regarding RQ 2, I counted the importance of psychological needs as specified by the participants. I translated direct quotes into English and used the following conventions for pseudonyms: T for teachers, R for researchers, and L for learners (T-03). The full transcripts are available in an online supplement (https://rohl.es/dissertation).

Fig. 28: Affinity diagram of the role of psychological needs in digital concept mapping

4.5 Results

4.5.1 Experiences With Knowledge Visualization Methods (RQ 1)

In general, visualizations were experienced as helpful for creating understanding because they reduce textual materials (T-01: “because relations can be represented better than with a text”). Being able to deal with complexity in knowledge and problem-solving was considered a vital “21st-century skill” (T-04; T-02), and thus, visualization methods are “simply another tool that the children get to enter the business world later” (T-02). Acquiring the skill of concept mapping is seen as an educational advantage for learners: “The concept mapping or simply this yes I have a problem, how can I model the problem, that is something that later is needed anywhere in engineering. […] People with these skills are massively missing” (T-04).

In line with research on active learning (Freeman et al., 2014), participants particularly emphasized actively creating visualizations because they result in “a higher activation that is that people work on the things themselves, that they have […] learning experiences instead of listening” (T-07).

Although the participants expressed a deep interest in concept mapping, many did not have practical experiences with the method. However, they quickly understood the idea of concept mapping and expressed several advantages. For example, T-06 emphasized that “as a teacher I quickly see whether he is on the right path”. The labeling of links was emphasized for making semantic relations explicit because if “the lines are indifferent then I do not know what they meant” (T-08). A small number of participants had experiences with collaborative concept mapping for complex problem-solving and emphasized the value of concept maps for discussing solutions to a problem, in particular because collaboration allows identifying new perspectives: “I have used logic and thought […], but I did not think about other consequences. And only when I spoke to others […] I discovered: ok, there are also other relations” (L-01).

Finally, participants reported experiences with several other visualization methods. Mind mapping is frequently used collaboratively in class (for example, collecting existing knowledge or ideas of learners) or individually (for example, for brainstorming, summaries, repetitions, or planning of activities). However, despite its popularity, participants also reported challenges with mind mapping, especially that they are not structured enough. Consequently, several participants reported that learners sometimes dislike mind mapping because “some students are at least at the beginning a bit weary of it” (T-08).

4.5.2 Psychological Needs: Importance (RQ 2) and Reasons (RQ 3)

Table 7 contains the importance ratings of psychological needs. I combined positions after number 3 because several participants either specified that they have equal importance or did not want to put these needs into a particular ordering. Furthermore, I included a column labeled “neg.” (for negative) because some participants actively disliked a psychological need. The column “reasons” contains main reasons for the choice as specified by the participants.

***Table** 7: Importance ratings for psychological needs and the reasons (N = 17)*

Need	Importance ratings					Reasons
	1st	2nd	3rd	> 3rd	neg.	
pleasure & stimulation	5	6	3	3	–	(1) understanding topics and increased motivation (2) hedonic user experience (3) collaboration
competence & effectiveness	3	5	2	7	–	(1) methodological competence for concept mapping (2) understanding structural relations
security & control	3	1	5	8	–	(1) master complexity (2) controlled collaboration (3) destabilizing without feeling lost
relatedness & belongingness	3	–	3	10	1	(1) semantic relations (2) feeling connected to others (instructors & learners) (3) potential source of bias in collaboration (negative)
autonomy & independence	2	2	3	10	–	(1) deciding on one's learning (2) being autonomous in concept map creation
self-actualizing & meaning	1	3	1	11	1	(1) understanding the purpose of learning (2) meta-cognition (3) self-actualizing through collaboration
influence & popularity	–	–	–	12	5	(1) biasing results (negative) (2) limit influence (3) helping others

4.5.2.1 Pleasure & Stimulation

The need for pleasure and stimulation was the most prominent psychological need. The main reason for creating pleasure is related to understanding a topic and acquiring new knowledge because "it creates pleasure if you have decomposed such a complex topic into its parts and can explain the relations" (T-05). Such pleasure is experienced as stimulating and, ultimately, motivating (T-02: "If you have fun than it sticks, you are interested, you are motivated and often you want to know more about the topic"). Instructors emphasized they invest a lot of effort into "making the teaching somehow engaging" (T-05) and expressed desired outcomes that a digital concept mapping tool could support such engagement: "that simply moving these terms around and trying to become conscious of in which relation they stand, that this alone creates more fun and more pleasure and is more motivating" (T-08).

The second set of reasons addressed how pleasure is created in digital concept mapping. Several participants connected pleasure to aspects of hedonic user experience, thus emphasizing that technology is itself a source of pleasure (Hassenzahl, 2010), such as T-07: "It depends on how you do it, too, these aesthetic and sensory pleasures in the, I mean, if it is presented beautifully then it can really create pleasure".

Finally, instructors and researchers emphasized the role of collaboration for creating pleasure: "I think or have made the experience that if they note down these terms in groups […] they have more fun or pleasure doing this and more discussions then if we simply together on the black board and one raises one's hand and the rest is little to not interested at all" (T-08).

4.5.2.2 Competence & Effectiveness

The need for competence and effectiveness was the second most prominent psychological need in the study, mainly for reaching specific, concrete learning goals because students "want to get something concrete at hand [and …] want to know: what can I do with this?" (T-07). However, participants also stressed that concept mapping could be challenging to acquire because "developing the competence, that is the skill to master the method and deal with it, that is a very highly weighted learning step itself" (R-02). Thus, helping learners acquire this concept mapping competence is the first step in establishing the method, indicating a necessity for instructional guidance and onboarding.

The second group of reasons related understanding structural relations to being able to "explain relations effectively" (T-05) and turning these insights into a deeper understanding, such as meta-cognition (L-02: "sometimes I know that I had something in my head, and then I wrote it down or typed it down, and suddenly, no I miss that, I miss the structure. A tool that allows me to structure myself, that would be great.") or learning from others (T-03: "You are you get feedback from the students: what do they know that I maybe not know yet or where I do not have that much insight yet").

The need for competence and effectiveness was also connected to other needs. T-09 mentioned its relation to self-actualizing and meaning: "If you have the competence, even if maybe you do not know it that this is included here somewhere, that they think afterwards: oh, I know more than I thought, or I can do more than I thought, and advance this and then come to self-actualizing maybe". For L-05, competence and effectiveness were connected to the need for security and control: "that when you are competent and effective you somehow also have security and control of your learning. Yes, if you are not competent and it goes wrong then you do not have the security anymore. Then you put yourself into question." Finally, R-03 criticized competence as too individualistic.

4.5.2.3 Security & Control

The need for security and control was positioned frequently in the top three of the needs, mostly because it was associated strongly with having a feeling of controlling complexity so that "the many complex things do not overwhelm me, but that I took them and said: so, you go there, you go there, you got there, you come here, that means I still have the control, I can structure them" (T-07). This notion of control was associated with "the feeling of being sure that you have understood it, that you master the notions […], that is the control I think that this is important" (L-02).

The second reason for choosing security and control was the idea of having a certain control over collaboration, in particular regarding having constructive discussions. L-01 used the term “degenerate” to denote unwanted destructive discussions or deviations from the topic: “That it does not degenerate, that it stays serious, that not everyone does whatever they want only, but that it is taken seriously somehow. Em that it does not degenerate but stays in its framing”.

However, a certain feeling of insecurity was also expressed as a wanted effect of dealing with complex problems to feel destabilized without feeling lost. R-01 explained that it is “the method has to encourage you to think differently, has to destabilize in a certain way but keep you nonetheless at a level that you do not feel lost”. Collaboration was emphasized as key to maintaining this balance (R-01: “this degree is easier to hold if you discuss things together, if you work with the method together, and if you get feedback from your peers”). A digital concept mapping tool could contribute to keeping this balance but also risks creating a “false security” due to the representative nature of concept maps (R-02: “The method suggests a feeling of having understood it when you wrote it down. […] that is not desirable because it can lead to that maybe highly selective insights suddenly become dominant”).

4.5.2.4 Relatedness & Belongingness

The need for relatedness and belongingness scored relatively high in importance, but three participants understood it as semantic relations of concepts, closely related to the need for competence and effectiveness (T-05: “with the relations, it is not about a relationship I mean I do not see it as relationships between humans but as a relation in a structure on different layers”). Participants who did not interpret relatedness in terms of semantics discussed it on a general level in education. For example, T-06 suggested that a feeling of relatedness is a prerequisite for a relation of instructors and students.

Participants furthermore discussed relatedness and belongingness in collaboration. Some participants stressed that feeling related is important for collaboration, but this notion of relatedness was not universally positive, particularly because it might bias the results. For example, R-03 emphasized that “the map, if used collaboratively, should be something connecting […] but not created on the basis of ‘we want to collaborate in harmony’ and without any content which is relevant.” Concept mapping could, thus, spark meaningful discussions about topics but should not lead to discouraging fruitful disagreement.

4.5.2.5 Autonomy & Independence

Seven of the sixteen participants positioned autonomy and independence among the top three psychological needs. Autonomy was associated with deciding on one’s learning. Concept maps hold the potential to empower learners to find their approach to structuring topics instead of following predefined procedures, for example, L-05: “autonomy and independence, that I do not get told what how what and how I should do it […] And somehow I think that it takes you autonomy and independence if you cannot decide freely how you structure something.” Consequently, participants emphasized that learners should be able to create concept maps autonomously without relying on external help.

4.5.2.6 Self-actualizing & Meaning

The need for self-actualizing and meaning was less emphasized, with only 5 participants mentioning it in the top three positions. In discussing the reasons for their choices, participants frequently referred to understanding and relating to the purpose of what is being learnt as a basis for self-actualizing. Understanding the purpose of concept mapping is experienced as vital by learners (L-01: "In my group, there is at least one person where I think, this person still does not understand why he has created this map. […] Em but it is very important and he has simply not understood it and he has to understand that it helps."). Instructors emphasized that they have to communicate the purpose of concept mapping.

The second group of reasons focused on meta-cognition. Learners get a deeper understanding of their cognitive processes, for example, by understanding the thought processes of others (R-02: "that sound a little, of course they cannot observe your thinking but they can observe how your connected thoughts manifest, how this is visualized"), identifying weaknesses (L-03: "I would say that with a software that is learner-centered, it would allow them to correct if there is a weakness or to select what they really like to do and go into detail"), or being creative (T-05: "here is this element of creativity. Yes hm hm. It requires creativity to create a concept map").

Finally, the need for self-actualizing and meaning was often considered an outcome of collaboration. For example, T-04 suggested that fruitful discussions resulted in a deeper understanding of personal shortcomings. Participants frequently suggested that a digital concept mapping tool could encourage such a reflection by making different views visible.

4.5.2.7 Influence & Popularity

The need for influence and popularity is the only need that none of the participants mentioned in the top three priority, and even further, it is criticized by five participants. Some participants criticized it as traditional, instructor-led education (T-07: "this is in principle what we do not want. Being a person whose advice others seek and follow. This is the classical instructor-student relation"). Instead, participants suggested that the focus should be on the learners, without risk of being biased (L-02: "if it is a concept map for myself, I do not need to be influenced, this is not the goal. It would be more for me than being biased by someone else").

The second group of reasons focused on how the influence of individuals could be limited to give each participant equal chances in collaboration. Different solutions were proposed, such as creating individual concept maps first and then discussing them in the group, or directly intervening (R-03, pos. 64: "I would always I mean I do it rarely if it is very obvious then I encourage actively that others should be involved. But this is obviously very direct, very disturbing in the flow and somehow interrupting the process of concept mapping."). R-03 also expressed concerns about not being able to observe collaborative processes when they are mediated by technology ("Then it is no longer clear how strong the contributions are and who is dominating. And the chance is high that some people simply act as free riders or feel passed over, I think."). Interestingly, concept mapping could also encourage a critical self-reflection on one's influence on others. For example, L-01 explained that collaborative concept mapping made him aware of having tried to overly influence the group's opinion.

However, not all participants shared the negative view of influence and popularity. As the third group of reasons, T-02 stressed that influence could also mean helping others when "a student has difficulties in concept mapping for example, then another person, a student who can do it better, can help him".

4.5.3 Research Question 4: Ideal Concept Mapping Tool

4.5.3.1 Technologies for Digital Concept Mapping

Several participants discussed whether concept mapping should be paper-based or digital. Paper was often associated with simplicity, availability, and directness (T-06: "That would be one point […] that is much simpler because the medium, digital medium is not in between"). One participant explicitly preferred paper-based concept mapping for these reasons, but other participants emphasized that advantages of the digital medium prevail, especially easy and rapid changes, flexible options for exporting and sharing, a potentially limitless canvas (R-02: "The paper has simply because it is square and has a particular number and you have to be able to read it em it limits the possibilities of representation."), and easy archiving (for example, with a dashboard that collects all concept maps of a class).

A majority of ten participants suggested a tablet as their preferred technological device for digital concept mapping. Two other participants suggested a hybrid laptop (R-01: "I think the combination is genius. […] for intuitive things: swiping left, right, moving, use the touchscreen, but in particular to provide the input to type: on a keyboard."). Touchscreen-based interaction was assumed to be more intuitive (T-01: "The second is that you do not have to use a mouse. And I think with the hand it is more intuitive.") and direct (R-01: "Because they have the direct contact, can point to it directly"), in particular because of positive associations with handwriting (L-01: "And humans are simply used to writing with the hand, and it remains better in your memory than typing some keys or so. It is simply more comfortable I would say the interaction, and I personally like this very very much."). Consequently, creating concept maps by hand with a stylus was emphasized by participants (L-01: "Em I use One Note very much because it has the very good possibility to draw with the pen […] Em when you draw a circle then it is not perfect but it […] makes it automatically perfectly round."). Such a combination of easy interaction with digital capabilities was emphasized as "a super tool [laughs] I would be really happy with it, that would be almost perfect" (T-06). Furthermore, some instructors suggested creating a presentation mode for collaboratively building or presenting concept maps on interactive whiteboards.

However, some participants actively disliked the tablet, in particular L-02: "the tablet, for me it is like the smartphone, it is going away like that. […] And suddenly I have difficulties concentrating." Instead, the participant suggested that using a computer means taking up a better position for learning. Age-related differences were also emphasized: While instructors referred to being more used to computers, they considered touchscreen-based interaction more appropriate for the younger generation.

4.5.3.2 Functionalities and Characteristics of Digital Concept Mapping Tools

Participants expressed tool ideas in four areas of concept mapping: assessment, collaboration, learning and concept map creation, and user experience.

First, several suggestions referred to formative assessment because “the aim is always to help, never to evaluate and give grades” (T-06). Participants emphasized that digital concept maps could automatically record the process of concept map creation, so that “you see in real time what is being written […] and maybe also register all that, I mean per video […] how the child creates the map, that this is registered so that you can always watch different parts again” (T-02). Instructors imagine such process data to help learners (T-04), not for deriving objective evaluations. Furthermore, participants expressed assessment ideas like calculating automatic scores based on graph theory (e.g., to identify clusters, R-02) or differentiating tasks for individual learners so that “students that have difficulties would have words where they could add something, or you could leave the words away for stronger students” (T-02).

Second, several suggestions concerned collaborative concept mapping. An ideal concept mapping tool should allow learners to create concept maps without requiring an account and enable synchronous collaboration on a concept map from multiple devices.

Third, several ideas concerned functionalities for learning and creation of concept maps. For example, participants suggested nesting concept maps into sub concept maps, integrating external resources, adding animations to visualize dynamic processes, or using visual features (T-02: “working with different symbols, for example whether I want a square, a rectangle, circle, whatever, with colors, with exclamation marks, question marks, these things, pictograms for example, that would be very important, the visual, that the visual is covered”). The overarching reason behind these suggestions is to help to deal with complexity because “if you can make dealing with this complexity possible and graspable by digital methods, by as I said filters, by colors, by em highlights, low high importance, however this is handled, then it can definitely help learning” (R-01). Participants emphasized that templates and wizards could help setting preferences for using these visual features.

Fourth, several ideas addressed aspects of user experience. Pragmatic user experience was a frequent concern because “when the tools are too complicated, this adds stress to us and we panic even more” (L-02). As a consequence, participants suggested help functionalities, a dedicated onboarding (T-08: “I would at the beginning, […] do I get a short tutorial that the people can simply, I think many teachers like that and I like it, too”), and a generally intuitive user interface (T-04: “The easier the whole thing the bigger are the chances that the whole thing is used by students”). Beyond pragmatic user experience, hedonic aspects were mentioned, in particular stimulating aesthetics (T-05: “I think such a tool when you create it should be somehow trendy. It has somehow the zeitgeist, the generation of today it has, it has to please them at first sight") or adapting the design to personal preferences (T-08: "if I could set the background, yes that it fits my topic without the image being too distracting").

4.6 Discussion

4.6.1 Concept Mapping in Luxembourgish Secondary Education

Research question 1 aimed at identifying experiences with knowledge visualization in Luxembourgish secondary education. The data indicate that concept mapping is not established in Luxembourg. Mind mapping is a popular method for different activities, but several participants emphasized that it is not structured enough. Concept mapping could fill this gap in the repertoire of educational methods: It could be used for similar educational activities like mind mapping but with a focus on a better structuring of the semantic relations and influences in a topic or problem[15]. However, concept mapping was itself considered a methodological competence to be acquired and has been described as a complex task (Amadieu et al., 2009; Sanchiz et al., 2019). Thus, a solid introduction to concept mapping is necessary that allows learners to build the required competence.

4.6.2 Role of Psychological Needs in Digital Concept Mapping

Research questions 2 and 3 aimed at identifying the importance of different psychological needs for digital concept mapping and the associated reasons, with the ultimate goal of contributing to a psychological needs profile (Desmet & Fokkinga, 2020) specifically for digital concept mapping:

- Pleasure and stimulation were rated very high in importance, mainly for stimulating learning (both regarding a topic and to using the method of concept mapping) and hedonic user experience.
- Competence and effectiveness were also highly relevant to build methodological concept mapping competence and understand a topic or solve a problem.
- Security and control were the third most important needs, in particular regarding feelings of mastery of the method and content of a concept map. Thus, it was experienced as very related to competence.
- Self-actualizing and meaning were associated with understanding and relating to the purpose of learning and meta-cognition. These aspects refer to the ultimate goals of concept mapping.
- Autonomy and independence were associated with the feeling of having control over the concept mapping and learning process.

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[15] The present study did not explicitly investigate how instructors and learners want to use concept mapping in their educational activities, but this question is addressed in Chapter 3.

- The social needs for relatedness/belongingness and influence/independence were discussed in settings of collaborative concept mapping, in particular in terms of setting a positive social context, but also as potential sources of biases when social relations impact the content expressed in a concept map.

The discovered role of psychological needs for digital concept mapping has the potential to design for a positive user experience, in line with a possibility-driven design approach (Desmet & Hassenzahl, 2012). Several suggestions for functionalities and characteristics of an ideal digital concept mapping tool (RQ 4) align well with the identified psychological needs and support suggestions that different psychological needs might be related to different dimensions of user experience (Hammer et al., 2018). In particular, the following hypotheses for design recommendations for digital concept mapping seem appropriate:

- Pragmatic user experience might be mainly associated with the need for security and control (Hassenzahl et al., 2010). Characteristics like an intuitive user interface and high usability are likely to impact the fulfillment of security and control. These might create the impression of being in full control of the concept mapping process.
- Hedonic user experience seems to be associated with the need for pleasure and stimulation. Characteristics like stimulating aesthetics and interactions are likely to impact the fulfillment of pleasure and stimulation. Furthermore, functionalities to freely express content in a concept map (e.g., including multimodal elements or adapting the visual design) could contribute to feelings of hedonic pleasure.
- Eudaimonic user experience might be associated with competence and effectiveness (building a skill that helps in addressing complex knowledge and complex problems) or self-actualizing and meaning (understanding the purpose of learning and building useful meta-cognitive skills). The suggested functionalities for formative assessment could allow instructors to provide guidance to their students on their way towards reaching these meaningful goals (Huta & Ryan, 2010). Likewise, the strong emphasis on visual and multimodal features could contribute to feelings meaningfully expressing content in concept maps.
- The needs of autonomy and independence might be associated with both pragmatic (being able to create a concept map independently, without relying on external help) and eudaimonic user experience (deciding autonomously on one’s learning). Functionalities like dedicated onboarding, useful help features, and practical templates could contribute to the fulfillment of autonomy and independence.

4.6.3 Functionalities and Characteristics of Digital Concept Mapping for Positive User Experience

Research question 4 aimed at identifying functionalities and characteristics for an ideal concept mapping tool, acting as guidelines for the following design. Besides the findings discussed in the previous section, several participants emphasized the general advantages of digital concept mapping, for example a potentially limitless canvas or easy editing of content. Furthermore, results indicate which technological devices should be considered for concept mapping. The tablet was more prominent than the computer in the present study. Tablets and computers differed in the associated qualities: Tablets were often associated with functionalities that cross pragmatic and hedonic quality. In particular, the strong preference for drawing concept maps by hand or with a stylus is an example of such a combination of pragmatic and hedonic qualities: On the one hand, participants emphasized pragmatic qualities like the directness and intuitiveness of such an interaction. On the other hand, participants were very enthusiastic about creating concept maps by hand, frequently mentioning hedonic qualities like strong emotions in favor of such an interaction style. Computers were almost exclusively associated with pragmatic user experience aspects, particularly the efficiency and precision of typing with a keyboard or pointing with a mouse.

Consequently, the findings indicate that an ideal digital concept mapping tool should be very flexible and available on many technological devices. However, they also indicate the requirement of extensive adaptations on different technological devices, including exploring completely different interaction styles. How precisely should these adaptations look like? What are their consequences in terms of user experience? And how do these adaptations relate to the idea of creating "an instrument whose interface could be used for both interaction schemes (keyboard & mouse and multi-touch)" (Weinerth et al., 2014b, p. 4)? This idea has driven the development of the foundational tool of the present dissertation since the very beginning. Further studies are necessary to answer these questions.

4.6.4 Limitations

Although card-based methods have proven useful in different stages of UX design (Wölfel & Merritt, 2013), an inherent limitation is that participants require time to assimilate the card set. The participants in the present study were not trained in psychological needs. Consequently, participants were possibly not able to benefit from the cards to their full potential. For example, three participants understood the psychological need for "relatedness and belongingness" in terms of semantic relationships between concepts (rather than social relations between people). I explained the cards and left them at the disposition of participants for verification. I also left extended room for discussions without a time limit. However, despite these precautionary measures, I cannot rule out that better training in using the cards might better allow participants to use them to their full potential. Furthermore, another limitation of the present study is the speculative nature of the results, as they are not based on using a real concept mapping tool. Thus, Chapter 8 will evaluate realistic experiences with concept mapping tools regarding fulfillment of psychological needs.

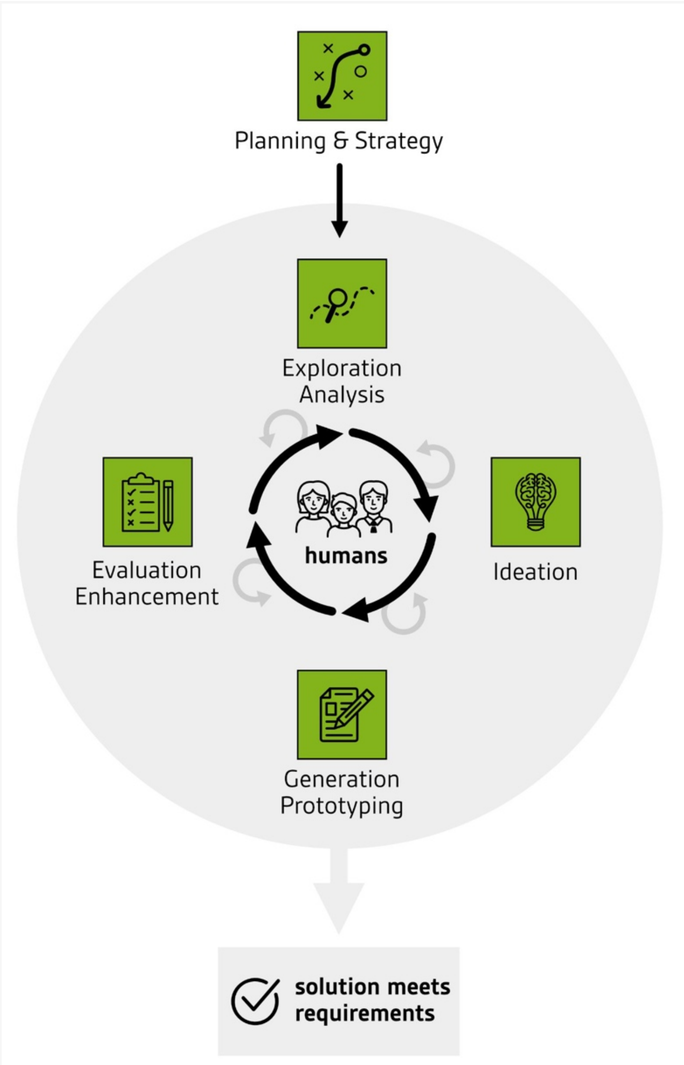
4.7 Conclusion

The present study aimed at exploring how to design for positive experiences in digital concept mapping with a particular focus on psychological needs. It addressed four research questions. First, it defined current experiences with knowledge visualization methods in Luxembourgish secondary education. The results indicate that concept mapping is not yet established but has the potential to address the lack of a knowledge visualization method with a focus on structural relations between aspects of a complex topic or complex problem. Second, it defined which psychological needs are particularly important for digital concept mapping. Pleasure and stimulation, competence and effectiveness, and security and control were promising for designing positive experiences. Third, it identified reasons for the choices of psychological needs, together with hypotheses for the relation of design and fulfillment of the respective psychological needs. These hypotheses are to be validated in the following design phase of the project (Chapter 8). Fourth, it identified functionalities and characteristics for an ideal concept mapping tool as specified by the participants. These ideas will be combined with findings from other studies to define a base of requirements for designing a digital concept mapping tool (Chapter 5).

5 Conclusion of Part II

The goals of users are at the core of a human-centered design process (Fig. 29). The three studies described in Part II defined key considerations for user experience in digital concept mapping. The insights serve two objectives. First, they provide the foundation to establish a human-centered, experience-driven design process for digital concept mapping tools. Second, they serve to identify key areas for research. However, I want to emphasize that these two areas influence each other. For example, the prototypes I validated in the design studies (see Part III) served as concept mapping tools to collect data for the following research studies (see Chapter 11). Likewise, research findings (for example, regarding fulfillment of psychological needs in Chapter 8) informed follow-up design iterations.

Fig. 29: *Human-centered design process of the present dissertation*



5.1 Foundation of UX Design for a Concept Mapping Tool

The studies in Chapters 2, 3, and 4 constitute the exploration and analysis phase of the user experience design (see Fig. 29), intended to identify and prioritize requirements (Hartson & Pyla, 2012; Lallemand & Gronier, 2018) in three steps.

5.1.1 Benchmarking

First, I performed a benchmarking of 34 digital tools (available in Appendix B) to identify best practices and opportunities for differentiating our tool from other tools. Most of the tools in the benchmarking were concept mapping tools, but I also included mind mapping and diagram tools. Three information sources served for collecting the tools: First, I searched the web and app stores with keywords like "concept mapping tool" or "mind mapping tool". Second, I reviewed scientific literature and verified whether the mentioned tools are publicly available. Third, I included all tools mentioned by participants in the studies of Chapters 2, 3, and 4. I extracted information about supported functionalities (e.g., sharing concept maps with others) and interaction design (e.g., right-click to create a new element). I compared each user-derived idea with the benchmark to investigate its potential to set our concept mapping tool apart from other tools. Furthermore, I shared a selection of the benchmarked tools with the development team for inspiration in the following discussions.

5.1.2 Integration of the Developer Perspective

Second, I discussed all user ideas with the development team in charge of implementing the digital concept mapping tool. In particular, we decided that the digital concept mapping tool should be running both as a stand-alone version (in a browser) and as an integration into OASYS, an online assessment platform developed at the University of Luxembourg. In line with our human-centered design approach (see Fig. 29), I assigned most emphasis to characteristics and functionalities derived from user feedback. All studies in Part II allowed participants to share their ideas and requirements for the digital concept mapping tool. I collected all ideas and requirements as outlined in the previous chapters in MaxQDA and carefully went through the list. I combined ideas into categories and converted each category into user stories, e.g., "As students and teachers, we want a stimulating aesthetics to spark interest." Care was taken that no essential information was lost during this conversion. I added notes about concrete ideas of users, for example, that the above-mentioned intuitive interface should be "reduced to the bare minimum". I went through the list repeatedly to verify that all information was adequately covered.

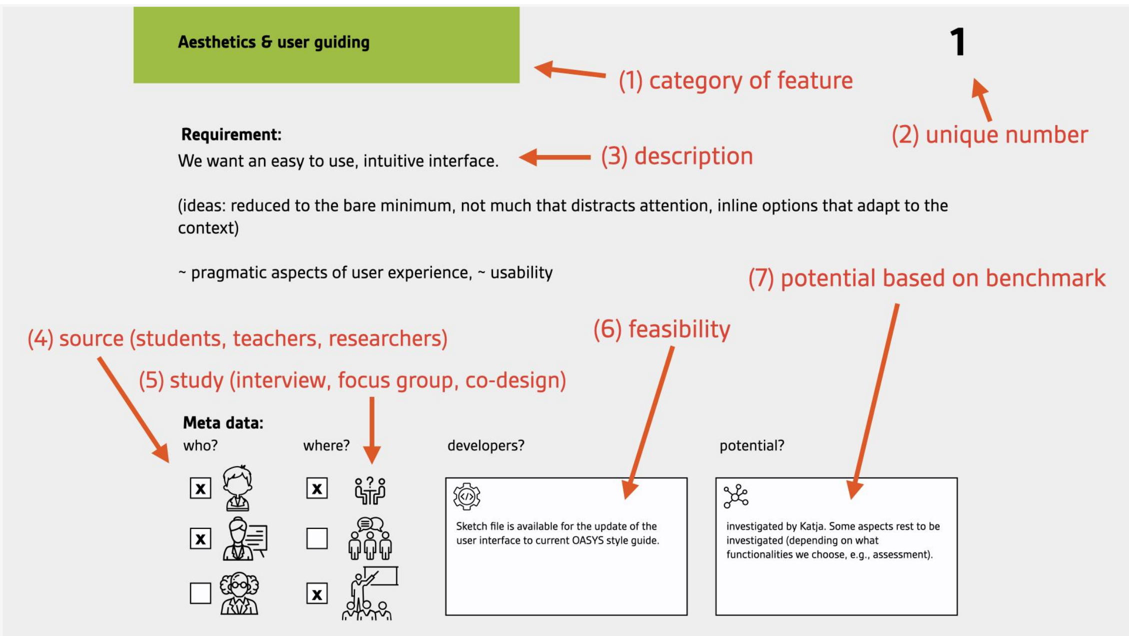
I met with the OASYS development team in December 2018 to discuss all collected ideas. The discussions served three purposes: a) evaluate the technical feasibility, b) align the requirements with the roadmap of OASYS, and c) involve developers as stakeholders. Thus, the discussions served to balance the needs of users and developers, safeguarding that developers' insights were adequately considered along users' requirements. Furthermore, we decided to build on prototypes created in a prior Ph.D. project (Weinerth, 2015) as a technological basis (see Chapter 6).

5.1.3 Prioritization of Requirements

Third, I synthesized all information collected so far to allow for prioritizing requirements. I created a card for each idea to synthesize essential information (Fig. 30). Each card contained:

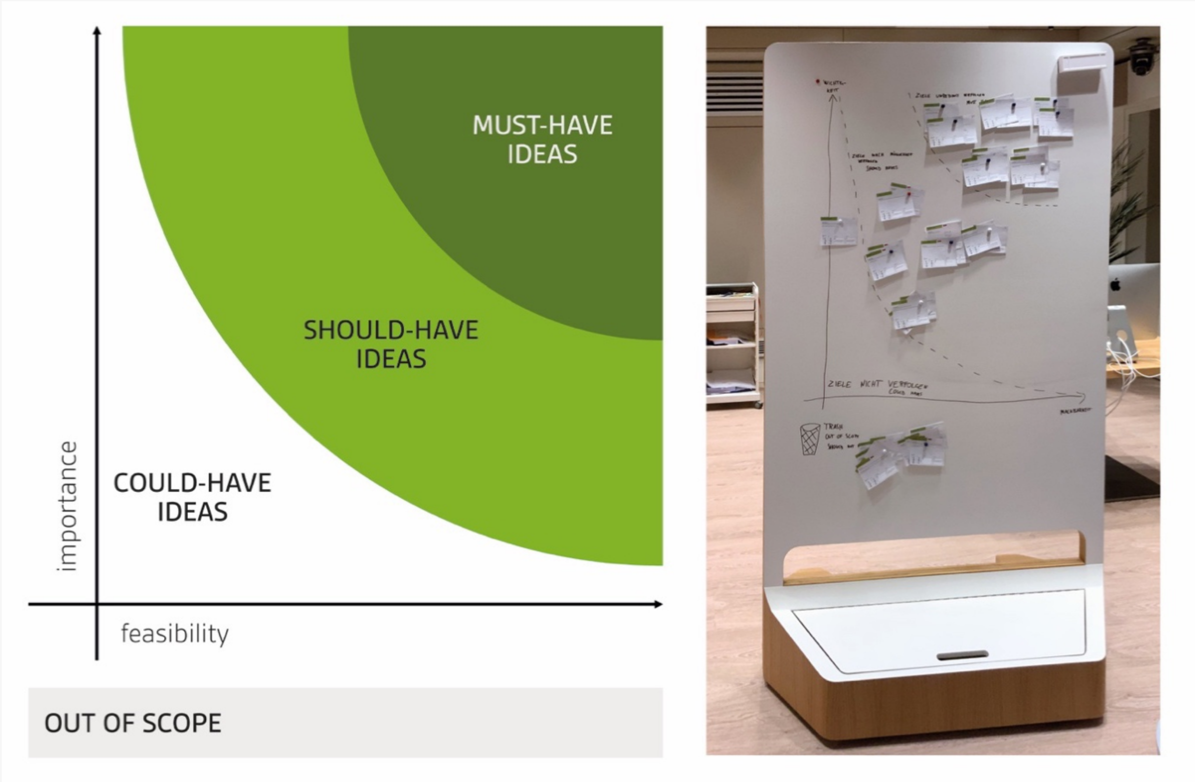
1. the category of a feature
2. a unique number for easy identification
3. a brief description, including suggestions from participants,
4. who suggested it (students, instructors, or researchers),
5. which study or studies that identified an idea (individual interviews focus groups with storytelling, or co-design workshops with classes; see Chapters 2, 3, and 4)
6. a summary of comments about technical feasibility from the OASYS developers,
7. an evaluation of the potential of an idea, based on a comparison with the benchmark

Fig. 30: *Example template for ideas*



Regarding the prioritization of the ideas, the researchers involved in the project went through the collection of idea cards to discuss a shared understanding and combined closely related cards. In total, 37 idea cards remained for further investigation. We created a matrix of feasibility and importance (Natoli, 2015). Fig. 31 presents an empty example. The matrix identified four categories of ideas: “out of scope” ideas (do not implement), “could have” ideas (implement when time is left), “should have” ideas (implement), and “must have” ideas (implement in all cases). Each idea card was positioned in one of these categories. A presentation with the full results of the prioritization is available as an online supplement (https://rohl.es/dissertation).

Fig. 31: *Matrix of feasibility and importance (left), adapted from Natoli (2015); photograph of the whiteboard used for prioritizing (right)*



We identified the following functionalities and characteristics as “must-have” ideas:

- aspects of pragmatic user experience (e.g., usability optimizing)
- aspects of hedonic user experience (e.g., stimulating aesthetics)
- integration of multimodal features in concept maps (e.g., to enhance concept maps or specify the importance of different links)
- specific functionalities: auto-saving concept maps; sharing of concept maps via a link, sending a file, or printing; support for language features of the operating systems (e.g., spell-checking)
- assessment functionalities: scoring of concept maps, management of concept mapping tasks, implementation of logging functionalities

Part III outlines the design evolution of the digital concept mapping tool. The design iterations concentrated on the first three “must-have” ideas (pragmatic user experience, hedonic user experience, and multimodal features). The specific functionalities like auto-saving are mostly on a technical level, and the assessment functionalities require further research to define scoring methods and concept mapping tasks (see Chapter 10).

5.2 Key Areas for Research

5.2.1 Contexts and Devices for Digital Concept Mapping

Throughout Part II, we investigated contextual factors and technological devices for the digital concept mapping tool. The results suggested that a flexible digital concept mapping tool is required that would allow for various use cases (see Chapter 3). Consequently, I decided to explore a broad range of contexts in my studies.

Furthermore, the participants in the studies in Chapters 2 and 4 expressed no general preference for which device they prefer for concept mapping, indicating that the digital concept mapping tool should support both computers and tablets. The follow-up studies had to investigate both devices. However, users were aware of interaction conventions on different devices and frequently expressed the need for optimizations for the input modalities of a device (e.g., hand-drawing of concept maps on tablets). Investigating such touchscreen-based interactions is one of the key areas for UX design in Part III.

5.2.2 Investigation and Optimization of User Experience

Evidence suggests that users are well aware of digital products' pragmatic and hedonic qualities and expect these pragmatic and hedonic qualities from tools for digital education, similar to commercial products. Users expressed strong preferences for an intuitive, easy-to-use user interface. Several ideas covered pragmatic functionalities to address pain points with regards to digital concept mapping. For example, participants suggested onboarding, help functionalities, auto-saving of concept maps, and easy sharing (e.g., export as PDF or image files and printing). Other ideas covered hedonic functionalities like stimulating aesthetics or customizing the user interface color. I will investigate a selection of these ideas in Chapters 7, 8, and 11 as part of UX design. Furthermore, I investigate the impact of user experience on digital concept mapping in Chapter 11, namely its relation to fulfillment of psychological needs, intention to use, and concept map scores.

5.2.3 Multimodal Concept Mapping

Another overarching theme was the need for functionalities that allow users to creatively express and enhance content in concept maps beyond the pure textual content, particularly including various multimodal documents and adapting the visual design of concept maps. For example, participants emphasized that multimodal features could help to distinguish important and less important elements in concept maps. I will investigate multimodal features in digital concept mapping in four studies, particularly their implementation in design (Chapters 7, 8, and 11) and their use to enhance digital concept maps meaningfully (Chapter 12).

5.2.4 Scoring of Concept Maps

Across all studies, participants expressed a need for using concept maps for assessment, expressing that concept maps might help learners identify their strengths and weaknesses (Chapter 3). However, deep insecurities about concept map scoring became also apparent. Thus, identifying scoring methods and concept map tasks appears to be a vital component of a successful digital concept mapping tool. I will address these concerns in Chapter 10.

PART III: UX Design for Digital Concept Mapping

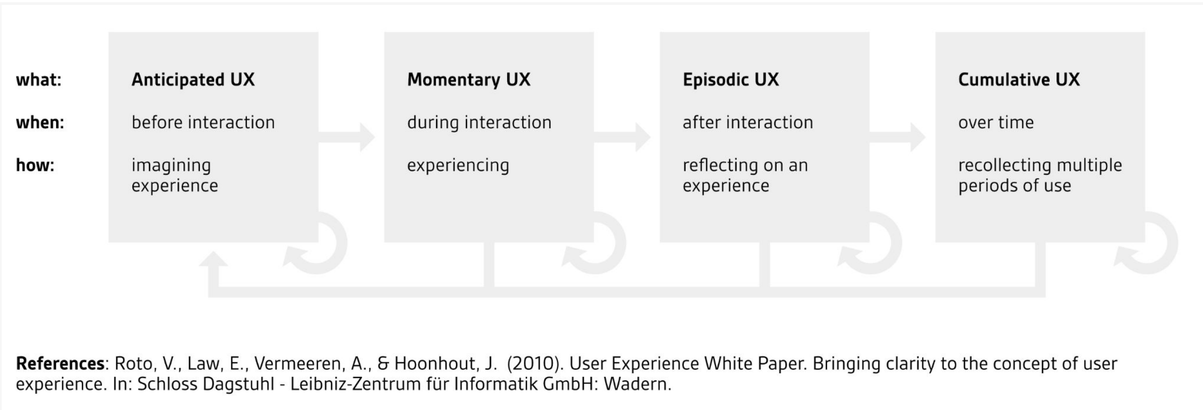
6 Outlining the Evolution and Evaluation of a Concept Mapping Tool Design

This chapter describes the design evolution of the digital concept mapping tool developed in the present dissertation. The design followed three main considerations.

First, as outlined in Chapter 4, two focus areas of experience design are solving problems or creating possibilities (Desmet & Hassenzahl, 2012). Solving problems of technology use is characteristic of problem-driven design (Ney & Meinel, 2019) to create satisfaction (Desmet & Hassenzahl, 2012; Hassenzahl, 2010; International Organization for Standardization [ISO], 2018). In contrast, possibility-driven design attempts to create positive experiences with technology use (Desmet & Hassenzahl, 2012), in particular by designing for happiness (hedonic; Diefenbach et al., 2014a) and meaningfulness (eudaimonic; Hammer et al., 2018; Mekler & Hornbæk, 2016). User experience encompasses both of these areas: doing something ("do-goals"; pragmatic, instrumental goals) and being (or becoming) someone ("be-goals"; hedonic, non-instrumental goals; Hassenzahl, 2010; Thüring & Mahlke, 2007). Throughout Part II, I have identified do-goals and be-goals in digital concept mapping. However, I have not so far implemented these findings into a digital concept mapping tool.

Second, user experience encompasses different time spans (Fig. 32). The findings from Chapters 2, 3, and 4 largely covered so-called anticipated UX: They addressed how participants imagined experiences with digital concept mapping. However, UX also covers momentary UX (during technology use), episodic UX (reflections directly after technology use), and cumulative UX (evolution of UX over time in repeated technology use; Roto et al., 2010). The design studies described in this chapter address momentary and episodic UX by describing real experiences with digital concept mapping prototypes[16].

Fig. 32: *Time spans of UX (Roto et al., 2010)*



[16] Cumulative UX remains an area of future work (see Chapter 13).

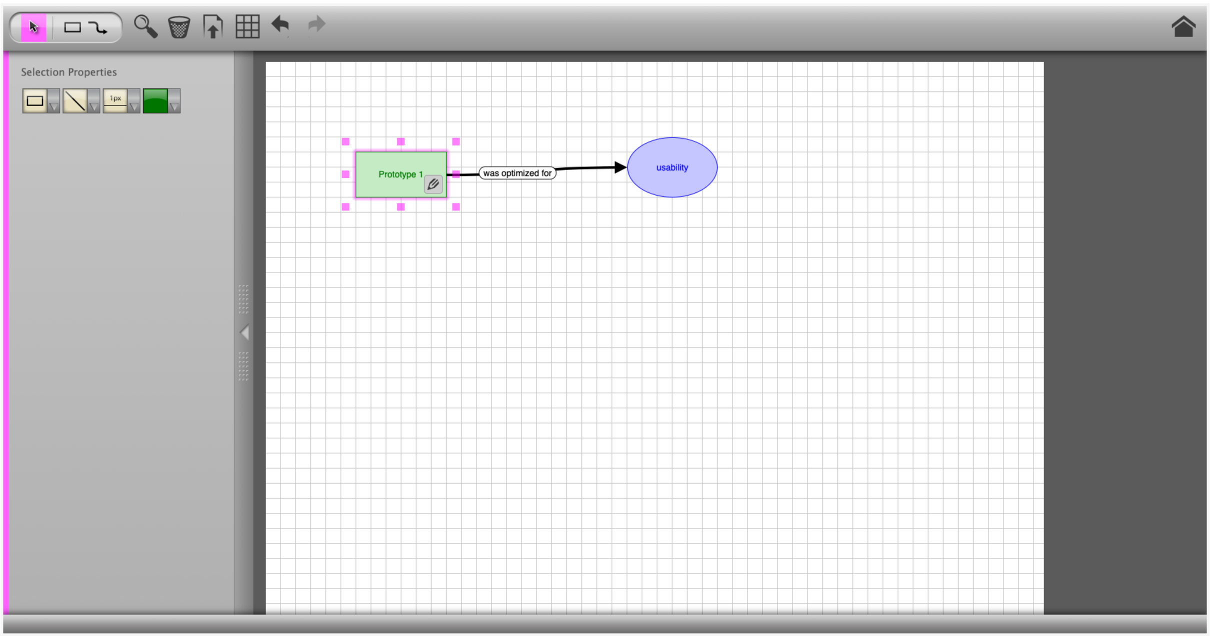
Third, the evaluations are formative (Hartson & Pyla, 2018; Scriven, 1967) and identify problems and opportunities for enhancing user experience, mostly through qualitative data. Although some quantitative measurements complement the picture, a statistical summative evaluation of user experience (Hartson & Pyla, 2018) is out of scope of the present chapter.

6.1 Prior Design and Development Work

The prototypes extend work of a prior Ph.D. project by Katja Weinerth (2015) (design and evaluation) and Eric François (design and development). In this project, three design iterations were created and evaluated with usability testing and heuristic analysis (Weinerth et al., 2014b). Furthermore, the final prototype was evaluated in a quantitative study in six schools (30 classes) in Luxembourg and Germany. This final version (Fig. 33) is the basis for this dissertation. The prototype is web-based and runs on all mobile and desktop browsers:

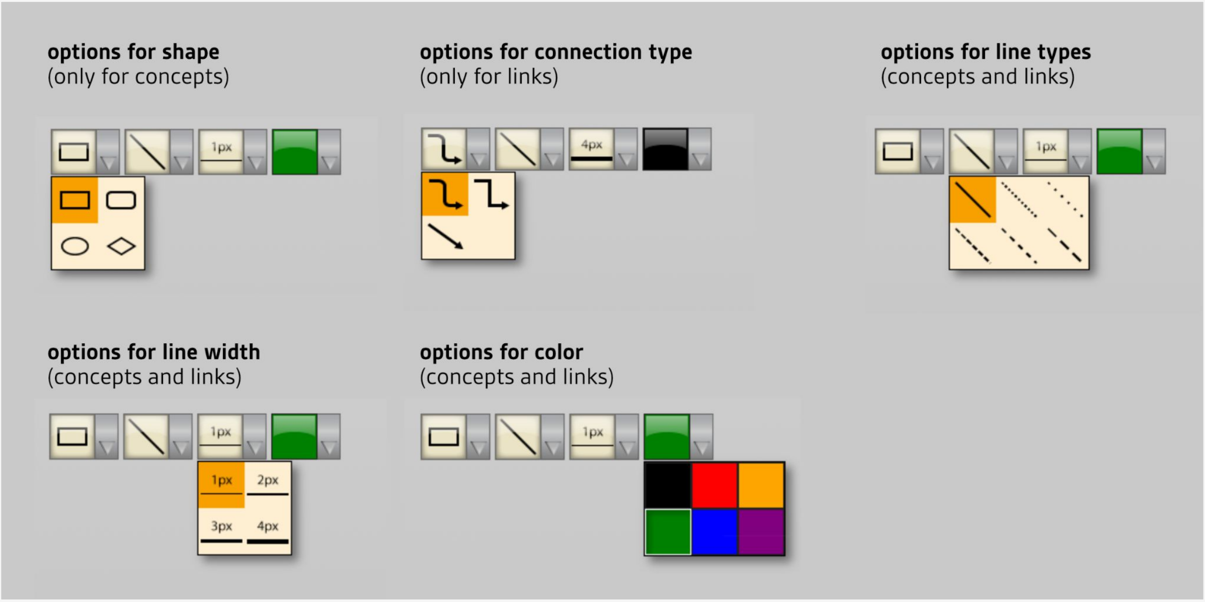
- The ***main controls*** are in the top menu. Options are in a **sidebar** on the left. Users can collapse the sidebar by clicking on the triangle on the border of the sidebar.
- The first three controls in the top menu are the main functionalities to create concept maps. They are color-coded: When activated, the sidebar's border color changes.

Fig. 33*: Final prototype created during the Ph.D. project by Weinerth (2015)*



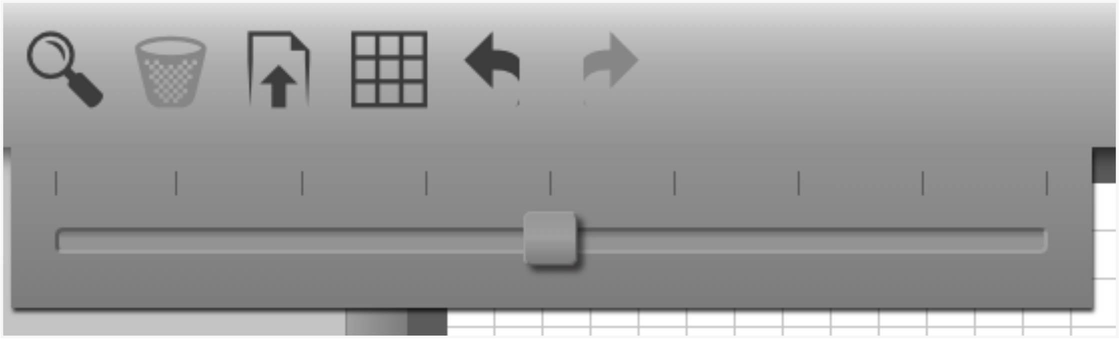
- The control on the left is a selection mode for selecting concepts or links. When an element is selected, the sidebar shows options to edit elements: shape or type of connection, line type, line thickness, and color. Each option opens a submenu with a limited choice of options (Fig. 34). Furthermore, each selected element has a small pen button (Fig. 33) to open a text field for adding labels. Finally, selected concepts have eight pink handles for resizing (Fig. 33).

Fig. 34: Options to design elements provided by the final prototype in Weinerth (2015)



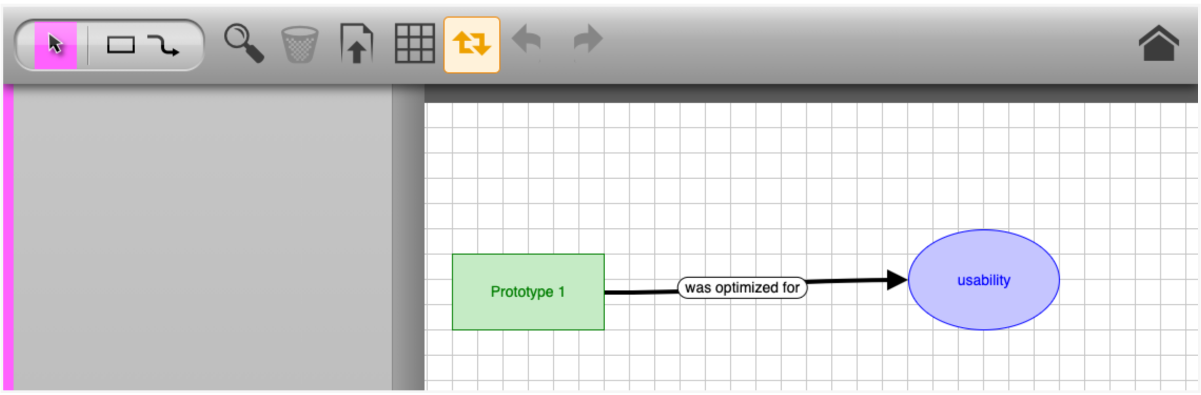
- The two remaining main functionalities are for creating concepts and links. Both have two modes. The first mode is “single creation mode”, available by clicking the menu icon once (depicted by a label “1x” underneath the menu icon). The second mode is “unlimited creation mode”, available by clicking the menu icon twice (depicted by an infinity symbol “∞”). All creation modes enable the design options in Fig. 34 to specify how the next created element should look.
- In single creation mode, clicking on the canvas creates a new element and automatically switches to selection mode. The created element is pre-selected, allowing users to edit design options or clicking on the pen button to add a label.
- In unlimited creation mode, clicking on the canvas creates a new element without switching to selection mode. Thus, users can create multiple elements in a row.
- In link creation mode, users can drag a pink preview line from one concept to another. Releasing the mouse button or finger on a concept creates a link. Releasing the mouse button or finger outside of another concept cancels the link creation.
- Options to edit the canvas or the document are in the right part of the main menu. Clicking the “zoom” symbol opens a slider to adjust the zoom level (Fig. 35). Clicking the “delete” symbol erases any selected element. It is only activated when an element is selected. Clicking the “upload” symbol saves a copy of the current concept map on the server. Clicking the “grid settings” symbol opens a panel with two checkboxes: one for showing or hiding the grid lines and one for selecting whether elements should align on the grid lines when they are created or dragged. Finally, “undo” and “redo” allow users to go backward or forward in the creation history of their concept map.

Fig. 35: *Zoom options in the final prototype described in Weinerth (2015)*



- Finally, several interactions are possible without a menu button. The canvas is movable by using the mouse's scroll wheel, moving the scrollbars, or dragging two fingers on a trackpad. Holding the mouse button while dragging in selection mode opens a pink selection area for selecting multiple elements. Users can also select multiple elements by clicking while holding modifier keys on their keyboard. These actions are only possible with hardware devices like a mouse, trackpad, or hardware keyboard, not on touchscreens.
- When opening the prototype on a touchscreen device, the menu contains an additional button for the "scroll mode" (Fig. 36). When scroll mode is activated, any action on the screen moves the canvas instead of creating or selecting elements. Users can still change to other modes (e.g., switch from selection to concept creation mode), but scroll mode overrides any action performed on the canvas.

Fig. 36: *Touchscreen prototype with activated "scroll" button*



6.2 Overview of UX Design Studies for Concept Mapping

During the requirements prioritization phase of the project, we decided that the final prototype described above should be the technological basis for the to-be-developed concept mapping tool. This decision allowed us to build on the extensive evaluation and development work (Weinerth, 2015), but several considerations made further design iterations necessary:

- First, around four years had passed since the work of Weinerth (2015). In the rapidly changing digital world, new user expectations have likely developed.
- Second, Weinerth (2015) focused on usability, not on user experience. In her user studies, she investigated effectiveness (scores achieved in concept mapping), efficiency (time needed to solve concept mapping tasks), and satisfaction (answers on Likert scales) to measure usability (Weinerth, 2015; Koenig, 2006). From these, only satisfaction partially overlaps with user experience, but several authors have pointed out that user experience extends satisfaction (Desmet & Hassenzahl, 2012; Hassenzahl, 2010; McCarthy & Wright, 2004). Consequently, user experience with the digital concept mapping prototypes has not been investigated so far.
- Third, the studies of Part II identified several functional requirements that are not or only partially covered by the prototype, in particular tablet optimizations or additional multimodal features.

In total, three design iterations with four prototypes were created and evaluated. The naming of the prototypes corresponds to their evolution throughout the design iterations. Prototypes a-1 and a-2 were investigated in the first design iteration (Chapter 7), prototype b-1 in the second iteration (Chapter 8), and prototype c-1 in the third iteration (Chapter 11). The first two studies were lab-based qualitative studies with the main purpose of evaluating the prototypes. The last study was a quantitative field study where we compared two prototypes (a-1 and c-1). Table 8 provides an overview of the studies.

***Table 8**: Overview of design iterations and evaluation studies*

Study characteristics	Chapter 7	Chapter 8	Chapter 11
participants	N = 35 (17 f, 18 m; 4 instructors; 31 university students)	N = 31 (17 f, 14 m; 4 school students; 27 university students)	N = 71
concept mapping task	highly restricted recreation of provided concept maps	free, unrestricted concept mapping, topic provided, no learning materials provided	semi-restricted concept mapping, suggested terms provided (concept, links, distractors), additions allowed, topic provided, learning materials provided
type of study	qualitative lab-based study	qualitative lab-based study	quantitative field study
tested devices	computers & tablets	tablets	computers & tablets
methodology	observation think-aloud UEQ (Laugwitz et al., 2008) debriefing interview with questions about user experience	observation with critical incident identification think-aloud UEQ (Laugwitz et al., 2008)	UEQ (Laugwitz et al., 2008) fulfillment and importance of psychological needs (Lallemand & Koenig, 2017)

		debriefing interview with questions about user experience interview on fulfillment of psychological needs with UX cards (Lallemand, 2015)	intention to use freeform qualitative feedback about prototypes and user experience
tested prototypes	prototype a-1 on computers: final prototype described by Weinerth (2015), visually updated, on computers prototype a-1 on tablets prototype a-2 with basic freehand drawing function	prototype b-1: enhanced based on feedback from the study in Chapter 7	prototype a-1, like in Chapter 7 prototype c-1: enhanced based on feedback from the study in Chapter 8 → undo/redo functionalities were removed

7 First Design Iteration

The main purpose of this study was to investigate the "status quo" of user experience (UX) with slightly modified versions of the concept mapping prototype developed by Katja Weinerth (2015) and Eric François to inform the design of follow-up iterations:

Research question: Which problems and opportunities exist to enhance user experience with the concept mapping tool in the following design iterations?

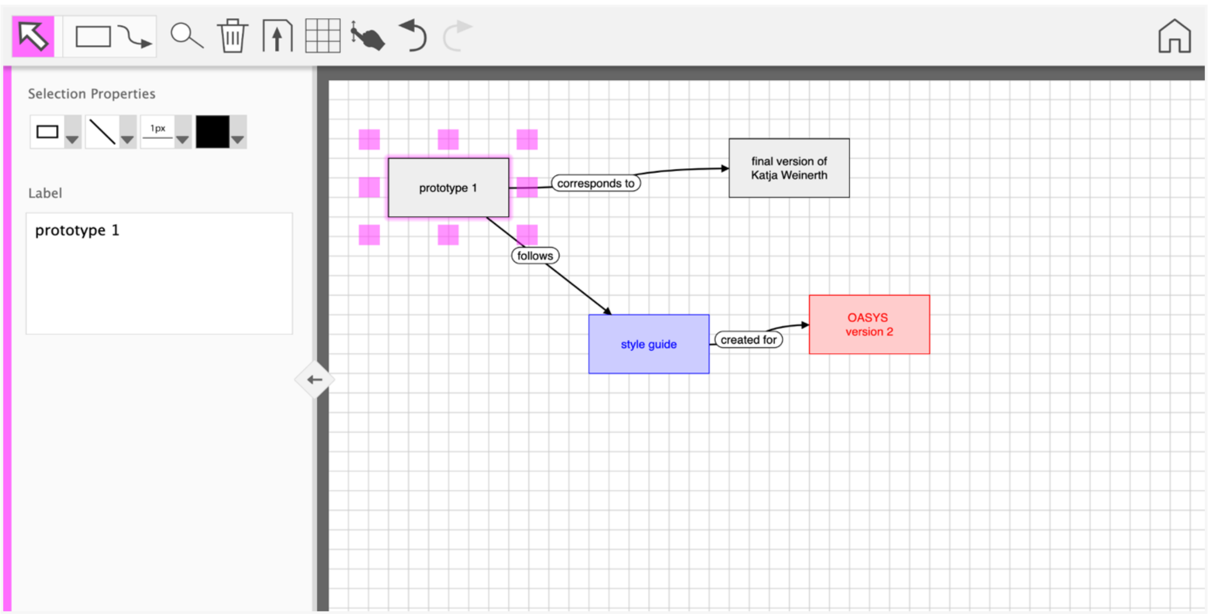
7.1 Methodology

The study took place at the user lab (University of Luxembourg, Belval). Each session lasted about one hour. Informed consent was collected before the study. For participants below 18 years, additional informed consent from parents was obtained. Participants could participate in German, Luxembourgish, French, or English. Participation was voluntary and compensated with 30 € vouchers. All materials and procedures were pre-tested.

7.1.1 Prototypes

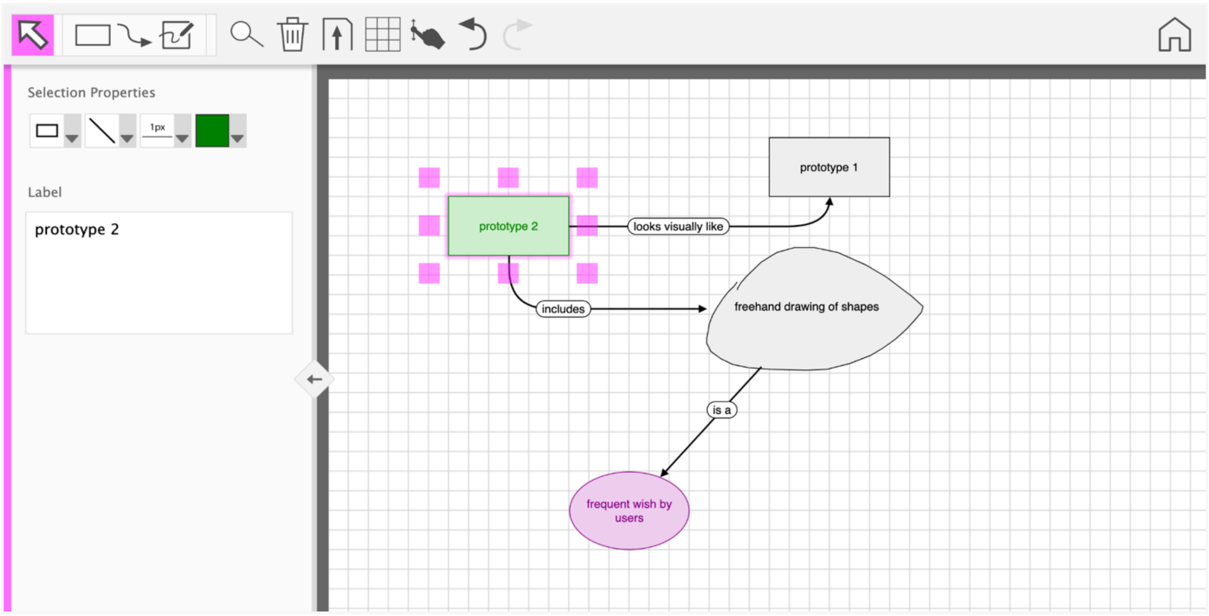
I tested two prototypes. Prototype a-1 was a visually updated version (Fig. 37) of the prototype described by Weinerth (2015), designed to follow the design style guide of OASYS. There were no functional changes. Participants tested prototype a-1 on computers and tablets.

Fig. 37*: Prototype a-1, visually updated from Weinerth (2015)*



Prototype a-2 (Fig. 38) investigated the potential of a tablet-optimized interaction design for creating concept maps. Numerous participants in the studies in Chapters 2, 3, and 4 suggested support for drawing digital concept maps by hand or with a stylus. I implemented a basic freehand drawing tool that converts the movements of the finger or stylus on the screen into a path and fills it with the specified color. Freehand shapes can be used for annotations (like exclamation marks) or integrated into concept maps like regular shapes.

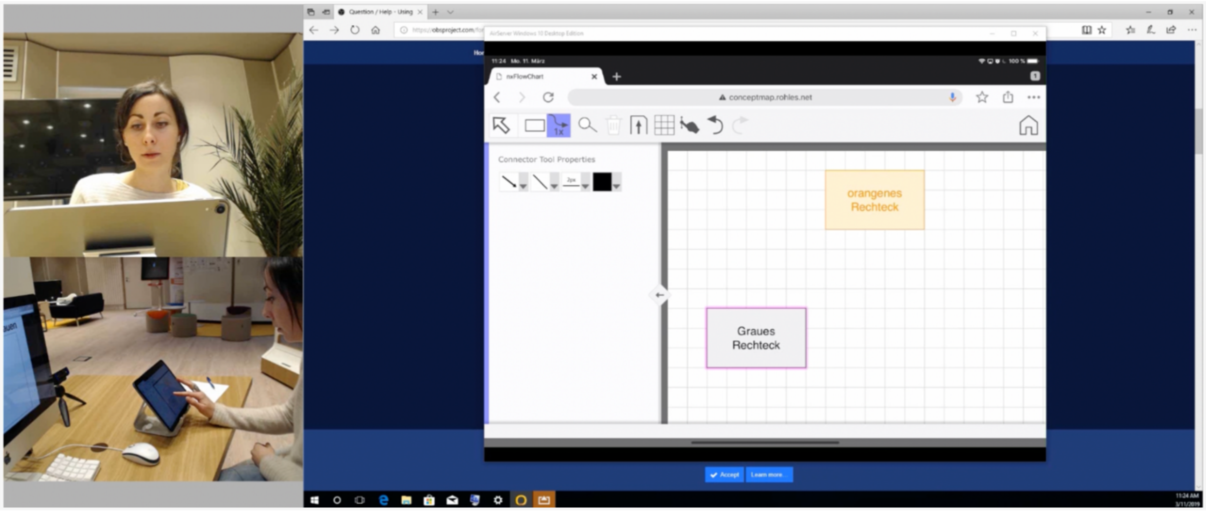
***Fig. 38**: Prototype a-2 with basic freehand drawing functionality*



7.1.2 Data Collection

I used a combination of quantitative and qualitative methods to investigate user experience, both during and after interaction with the prototype (Roto et al., 2010). Regarding experience during the interaction, I observed and recorded participants' interactions with the prototype and their reactions. I recorded the device screen, participants' faces and commentary, and participants' body movements (Fig. 39). Furthermore, I encouraged participants to verbalize their thoughts during the concept mapping task (think-aloud; Bilandzic, 2005; Ericson & Simon, 1980). The combination of observation with think-aloud is a standard methodology in user testing, appropriate for discovering both the objective behaviors and underlying reasons (Hartson & Pyla, 2012; Jacobsen & Meyer, 2019; Lallemand & Gronier, 2018). I explained the think-aloud procedure and reminded the participants to think aloud directly before the concept mapping task. A written note "please think aloud" was positioned next to the test screen as an additional reminder. I left the room during the concept mapping task to avoid any interference with the experiment. I observed the participants from the observation room (behind a one-way mirror) and took observation notes regarding users' behavior and think-aloud commentary for debriefing questions. Directly after the interaction, participants filled the UEQ (Laugwitz et al., 2008) as a quantitative measurement of UX.

Fig. 39: *Example recording (represented with permission) of participants' faces and think-aloud commentary (top left), body movements (bottom left), and tablet screen mirroring (right), synchronized via software*

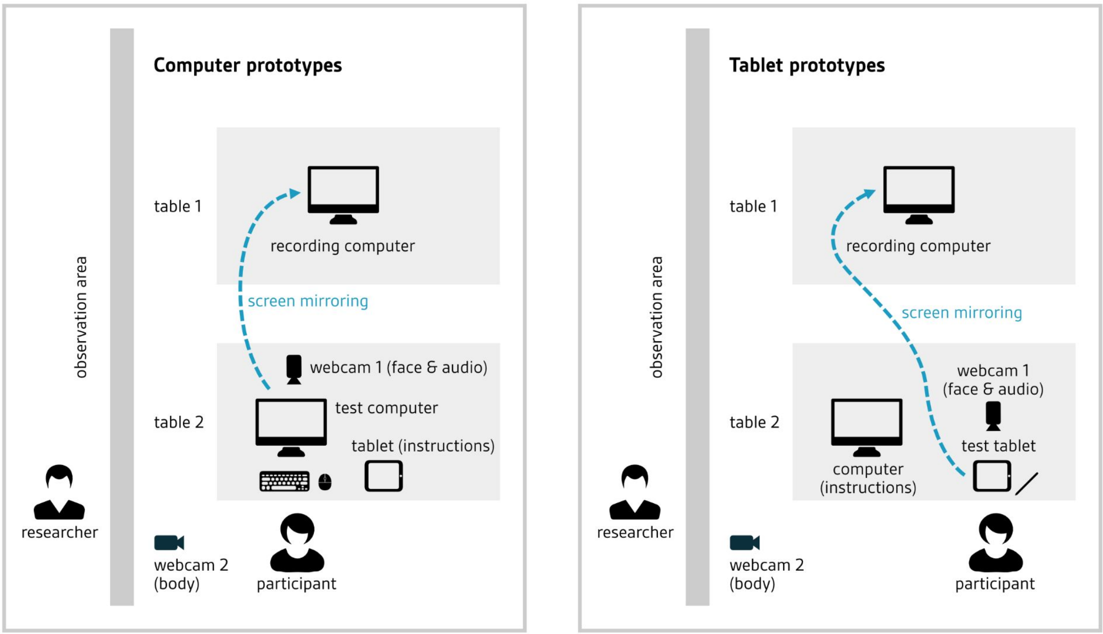


Finally, I met with the participants for a debriefing interview. I followed a pre-tested interview structure and asked non-leading questions to elicit deep qualitative feedback about user experience. First, the participants recapitulated positive and negative moments of their experience. Second, I asked questions about my notes to identify the reasons behind users' behavior and think-aloud comments. Third, I asked the participants to comment on all functionalities of the prototype systematically. Finally, participants had the opportunity to ask questions. The debriefing was audio-recorded.

7.1.3 Setting

The experiment took place in the user lab (Fig. 40). Participants were randomly assigned to one of the conditions (prototype a-1 on computers, prototype a-1 on tablets, prototype a-2 on tablets). Computer users used an iMac 21'' with keyboard and mouse, with the task instructions on a nearby tablet. Tablet users used an iPad Air 10.5'' with an Apple Pencil, with the task instructions on a nearby computer. A stand raised the tablet at a 45° angle (adjustable between 10 and 50°) for comfortable interaction (Fig. 41) and good recording quality.

Fig. 40: *Setup of the study on computers (left) and tablets (right)*



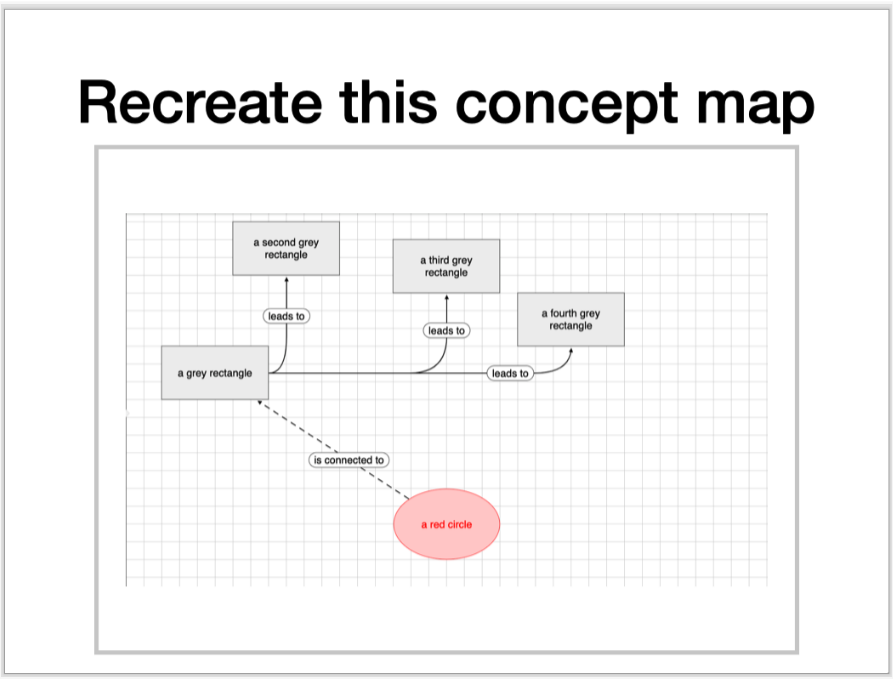
A computer running the software iMotions 7.2 captured and synchronized three input sources:

1. The screen of the test device (tablet or computer) was streamed to the recording computer using the software AirServer.
2. A webcam recorded participants' faces and think-aloud comments. The webcam was positioned directly to participants' faces immediately above the test device screen (see Fig. 41).
3. Another webcam on a tripod recorded participants' body posture and interactions with the test device.

Fig. 41: *Positioning of tablet and webcam 1*

Participants solved six consecutive tasks. The first four tasks required the participants to recreate a concept map (Fig. 42). The tasks grew in complexity and covered the full range of functionalities. The final two tasks were written as text instructions (“take away the last concept you created” and “save your document”). Care was taken to avoid any influence on the participants’ interactions, such as not showing any user interface elements. Participants could refer to the task description at any time, and there was no time limit for the tasks.

Fig. 42: *Example task from the study*



7.1.4 Analysis

I carefully listened to the debriefing audio recordings multiple times and performed a qualitative summarizing content analysis (Mayring, 2002) to code the essentials of participants' descriptions of their experiences. The codes were grouped in terms of functionalities (what the tool can do) and interaction design (how users interact with the tool to reach their goals). I also categorized the findings into positive and negative aspects to identify possibilities to design for and problems to solve (Desmet & Hassenzahl, 2012). Likewise, I went through my observation notes and the recordings of participants' interactions with the tool to identify positive or negative aspects left undiscovered. Furthermore, I derived a severity rating scale from 1 (only singular participants experienced an issue, and the issue had no strong impact) to 3 (about half or more of the participants experienced an issue, and the issue caused participants to fail or express strong emotions).

7.2 Results

In the following, I will concentrate on the qualitative results rated with a severity rating of 2 or 3. The quantitative UEQ evaluation will be presented in a dedicated chapter at the end of Part III, allowing for an easier comparison of the design evolution across different studies. A table with the full results is available in Appendix C.

In general, user experience ratings were encouraging. The **aesthetics** were typically evaluated positively (P4: "visually, it is well-made and well structured"), and several users stressed the **intuitive use** of the prototype (P17: "it was a great experience […] it surprised me in a good way, because it is user friendly"). Suggestions for improvement focused on two identified target areas: functionalities and interaction design.

7.2.1 Functionalities

One of the biggest problems in this study was the **auto-alignment of links**. More than half of the participants mentioned this issue during debriefing (P14: "the overlapping arrows do not look nice"). However, the task might have influenced the problem because it asked to rebuild concept maps, and slight deviations could lead to a very different flow of links: "if I would try to build a concept map from scratch I would probably not care that much but because I was copying a concept map I wanted it to look the same" (P23). A different task setting might answer whether participants accept the auto-aligning links when creating their concept maps.

Several possibilities to design for a positive user experience were also identified. Participants suggested an **onboarding** (P2: "It could be useful if there could be some tutorial at the beginning.") and more **multimodal features** (P31: "I would like to have more options, to make it more creative, more fashionable"). Some participants struggled because the color presets simultaneously adapt several colors without a clear preview (e.g., setting border colors in black and fill colors in grey).

7.2.2 Interaction Design

The distinction between **single and unlimited creation modes** frequently caused problems. In single creation mode, participants often expressed that the frequent need to switch from the pre-selection back to creation mode is cumbersome or accidentally applied changes to the pre-selected element (instead of specifying options to the next element). Thus, participants were generally favorable to unlimited creation mode, calling it "a pretty nice feature" (P10), but often discovered the functionality late or only in debriefing. In addition, unlimited creation mode caused considerable frustration when users accidentally activated it, often causing the creation of elements on top of others (P7: "I did not like the fact that there is this option, […] I accidentally had a red circle inside a red circle, because I hit this tool").

While creating concepts was readily understood, **creating and writing on links** often caused problems, for example, because the participants dragged an arrow from a concept to an empty space (P31: "I did not understand how to make the arrows. For me, it was not intuitive that I have to choose one rectangle and then to push the line."). Some participants also struggled with adding labels to links because of not finding the "edit" button on the links.

The tests on **tablets** revealed two further areas for improvement. First, the dedicated ***scroll mode*** caused frustration for around a third of participants who forgot when it was active: They scrolled to a new position, switched to a creation mode, and tapped the screen to create a new element, confused why the prototype would not create new elements. Similar difficulties were discovered for ***zooming*** because almost all participants found it unusual to have a dedicated zoom button instead of gestures (P16: "honestly, I would have expected that you would have used the touchscreen more, […] here I am basically using my hand as a single mouse pointer").

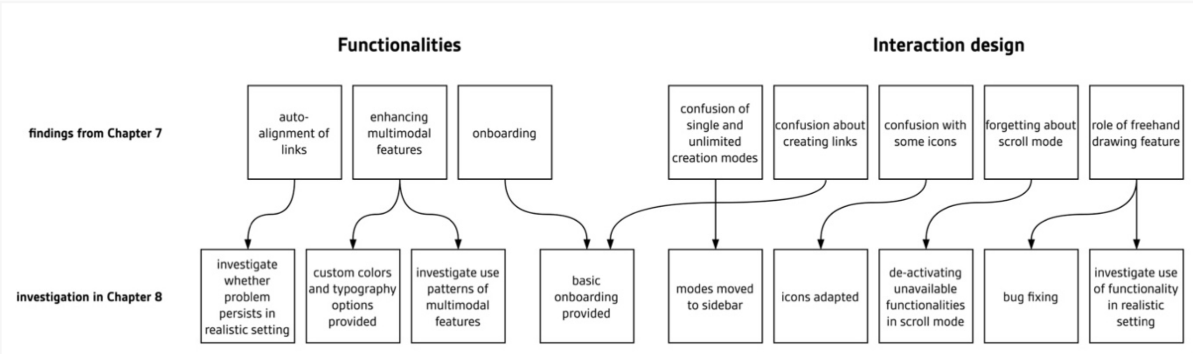
Second, the **freehand drawing** functionality was interesting. On the one hand, it was received favorably (P28: "it is pretty cool because you could make any shape"). On the other hand, some participants pointed out that it was not needed for the given tasks, indicating that the functionality should be re-examined in a more realistic task setting (P9: "You see that you have made it yourself, and this was not necessary for the tasks. […] But if you were to create something creative, then it is good that the tool exists."). Other participants suggested that the freehand shapes should be converted into regular shapes using shape recognition. The tests also revealed a bug when zoomed in, causing an offset between the position of fingers and freehand elements.

Finally, the findings revealed problems with some **icons**, namely the zoom, save, and selection mode icons.

7.3 Discussion

The study revealed a promising state of the prototype but also room for improvement. Fig. 43 summarizes the key design findings from this study in the upper section. These were selected to define the follow-up design iteration (Chapter 8). Specifically, I decided to address the ideas for enhanced multimodal features, onboarding, and the icons. Furthermore, I enhanced the distinction between single and unlimited creation mode, incorporated visual feedback that deactivates unavailable features in scroll mode, and fixed the identified bug in the freehand drawing tool. A detailed description of these enhancements is available in Chapter 8.

Fig. 43*: Overview of key findings for enhancements (Chapter 7) and implications for further prototyping (Chapter 8)*



8 Second Design Iteration

8.1 Three Key Considerations of the Present Study

8.1.1 Focus on Tablet-based Interaction Design

Similar to the study in Chapter 7, the main purpose of this study was to inform the design of a digital concept mapping tool with a focus on identifying problems to solve and possibilities to design for (Desmet & Hassenzahl, 2012). I decided to prototype and validate solutions for the central problems described in Chapter 7 (Fig. 43). Specifically, as numerous problems were more pronounced on tablets than on computers (e.g., the confusion about the scroll mode or selecting elements), I decided to concentrate on testing tablets in this study. Furthermore, I decided to concentrate on frequent opportunities to enhance UX as identified in Chapter 7, particularly multimodal features in concept mapping.

8.1.2 Investigation of Critical Incidents in a Realistic Task

User experience heavily depends on contextual factors (Roto et al., 2010), and some of my previous results suggest that findings might be less pronounced in a realistic concept mapping task (as compared to recreating existing concept maps), particularly the auto-alignment of links. Consequently, I wanted to raise the ecological validity of the study by investigating a highly realistic, low-directed task. This decision has the advantage of a realistic impression of user experience, but has also two main limitations:

- First, investigating different concept mapping tasks reduces comparability across the studies. I will return to this aspect in Chapter 9.
- Second, the realistic concept mapping task is less structured than the previous task in Chapter 7, and thus risks that some participants might not use every functionality. For example, Chapter 7 systematically made sure that all participants had to scroll and zoom to solve a particular sub-task, but in a realistic concept mapping task, some participants might not scroll and zoom at all. Furthermore, task-related aspects might impact user experience. For example, a slightly inconvenient design might feel deeply frustrating when users think hard about a task but might feel harmless when they are relaxed. Thus, I decided that a more systematic investigation of momentary user experience (Roto et al., 2010) is necessary as compared to Chapter 7.

As a consequence, I opted for a systematic observation based on the critical incidents technique (CIT; Butterfield et al., 2005; Flanagan, 1954) to gain deeper insights into how design decisions shape the momentary user experience. Critical incidents refer to moments with “a ‘significant’ contribution, either positively or negatively, to the general aim of the activity” (Flanagan, 1954, p. 338), including subjective and emotional experiences (Butterfield et al., 2005). In human-computer interaction, critical incidents typically denote events during the interaction with a product that might be indicative of usability and user experience issues (Hartson & Pyla, 2012). Thus, these events are well-suited for formative assessment of user experience and usability (Carroll et al., 1993).

Collection of critical incidents typically either involves observing an activity, using self-reports (either in retrospect or real-time) or a combination of both (Butterfield et al., 2005; Flanagan, 1954; Hartson & Pyla, 2018). In human-computer interaction, all of these methods have particular challenges. A challenge of observation-based collection of critical incidents is the so-called "evaluator effect", the tendency that different observers identify different critical incidents (Hertzum & Jacobsen, 2001; Howarth et al., 2007). Structured approaches to convert observation data into usability problems allow mitigating these evaluator effects (Howarth et al., 2007). Retrospective self-reports face the problem that critical incidents perish quickly in memory (Hartson & Pyla, 2018). Real-time self-reports interrupt the flow of interaction (Petrie & Harrison, 2009) or require additional reporting tools (Hartson & Castillo, 1998). As I was interested in a realistic concept mapping task in the present study, I did not want to interrupt the flows of interaction and cognition more than necessary. Therefore, I decided to identify critical incidents by combining observation and think-aloud self-reports by encouraging participants to verbalize significant moments during their concept mapping experience.

8.1.3 Psychological Needs in a Realistic Concept Mapping Task

Finally, I wanted to explore psychological needs to gain deeper insights into the reasons behind the user experience in digital concept mapping, picking up on research conducted in the study in Chapter 4. Psychological needs play a central role in well-being and positive user experience (Deci & Ryan, 2000; Hassenzahl et al., 2010; Hassenzahl, 2003; Tay & Diener, 2011). The present study is based on a synthesis of psychological needs suggested by Sheldon et al. (2001), as described in Table 9.

Table 9*: Psychological needs and definitions used in the present study (Sheldon et al., 2001, p. 339; Lallemand, 2015)*

Need	Definition
Autonomy and independence	"Feeling like you are the cause of your own actions rather than feeling that external forces or pressures are the cause of your actions".
Competence and effectiveness	"Feeling very capable and effective in your actions rather than feeling incompetent or ineffective".
Relatedness and belongingness	"Feeling that you have regular intimate contact with people who care about you rather than feeling lonely and uncared for."
Pleasure and stimulation	"Feeling that you get plenty of enjoyment and pleasure rather than feeling bored and understimulated by life."
Security and control	"Feeling safe and in control of your life rather than feeling uncertain and threatened by your circumstances."
Popularity and influence	"Feeling that you are liked, respected, and have influence over others rather than feeling like a person whose advice and opinions nobody is interested in."

Self-actualization and meaning	"Feeling that you are developing your best potentials and making life meaningful rather than feeling stagnant and that life does not have much meaning."

Chapter 4 identified the role of these psychological needs in digital concept mapping, including their relation to design:

- The need for **pleasure and stimulation** was the most emphasized psychological need in the study in Chapter 4, mainly for stimulating learning and hedonic user experience. The fulfillment of pleasure and stimulation might be enhanced by aesthetics and multimodal features that support creative expression.
- The need for **security and control** was mainly associated with feeling in control of complexity, and participants interpreted it in close connection to competence and effectiveness. The fulfillment of these needs might be enhanced by optimizing pragmatic enhancements, such as an intuitive user interface and high usability.
- Participants associated **competence and effectiveness** with methodological concept mapping skills and understanding structural relations of a topic. They associated **self-actualizing and meaning** with understanding and relating to the purpose of learning and meta-cognition. Eudaimonic user experience[17] might be closely related to these needs, for example, multimodal features to express content in concept maps meaningfully.
- The need for **autonomy and independence** was associated with feeling independent in creating concept maps and deciding on the learning content. The fulfillment of this need might depend on both pragmatic (e.g., useful tutorials) and eudaimonic aspects (deciding on a learning topic, relating oneself to the topic).
- The social needs (**relatedness and belongingness**, **influence and independence**) were frequently associated with collaboration. As I investigated an individual concept mapping task in the present study, I assume these play a minor role in this setting.

These findings from the study in Chapter 4 mainly cover anticipated user experience (Roto et al., 2010). In the present study, I wanted to investigate how a concrete, realistic concept mapping experience impacts the fulfillment of psychological needs.

8.2 Research Questions

Research question (RQ) 1: Which problems and opportunities exist to enhance user experience with the concept mapping tool in the following design iterations?

[17] It is important to emphasize that the exact relation of hedonic and eudaimonic dimensions of user experience is still to be defined and that there are likely areas where these two dimensions overlap. See Chapter 1 for a detailed discussion.

Research question (RQ) 2: How do critical incidents contribute to analyzing momentary user experience in digital concept mapping?

Research question (RQ) 3: Which psychological needs characterize the user experience in digital concept mapping?

8.3 Methodology

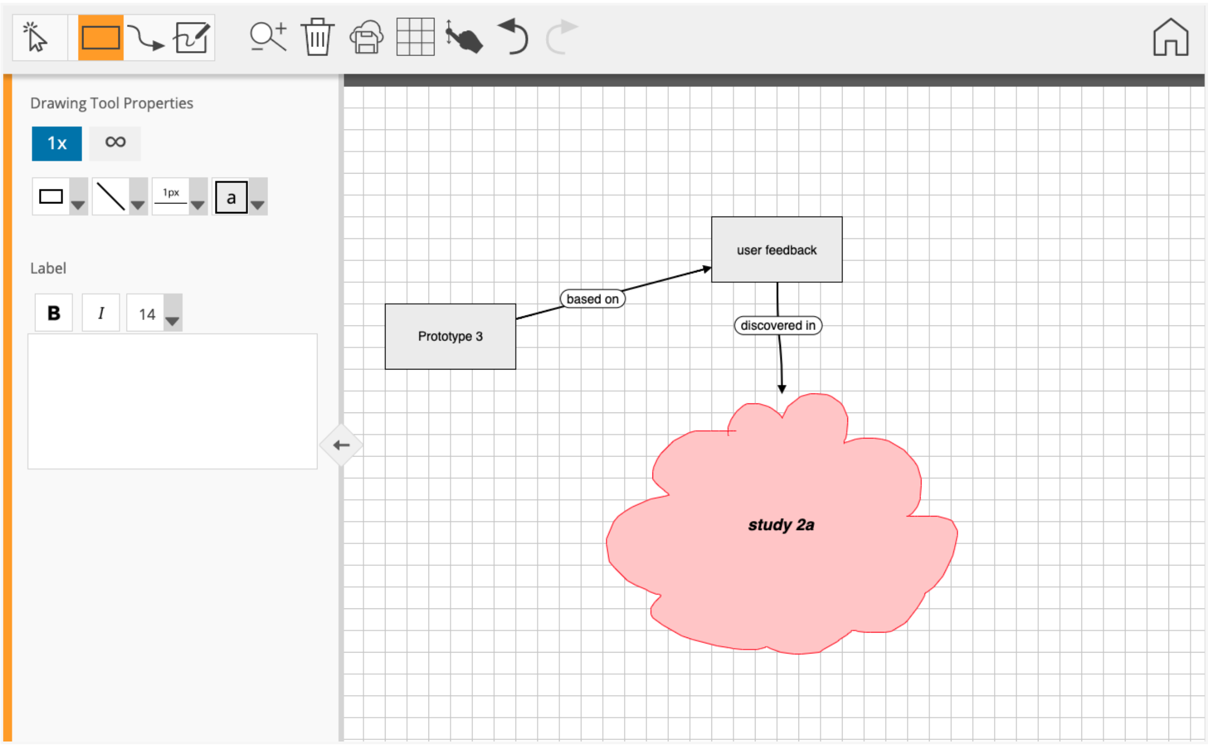
This study largely used the same methodology as the previous one (Chapter 7), with some adaptations for research questions 2 and 3. I will describe these adaptations here and refer to the methodology section of Chapter 7 for details about the general procedure.

8.3.1 Prototype

This study tested prototype b-1 (Fig. 44), a fully functional prototype designed to address the main findings from the previous study (Chapter 7). It implemented the following changes:

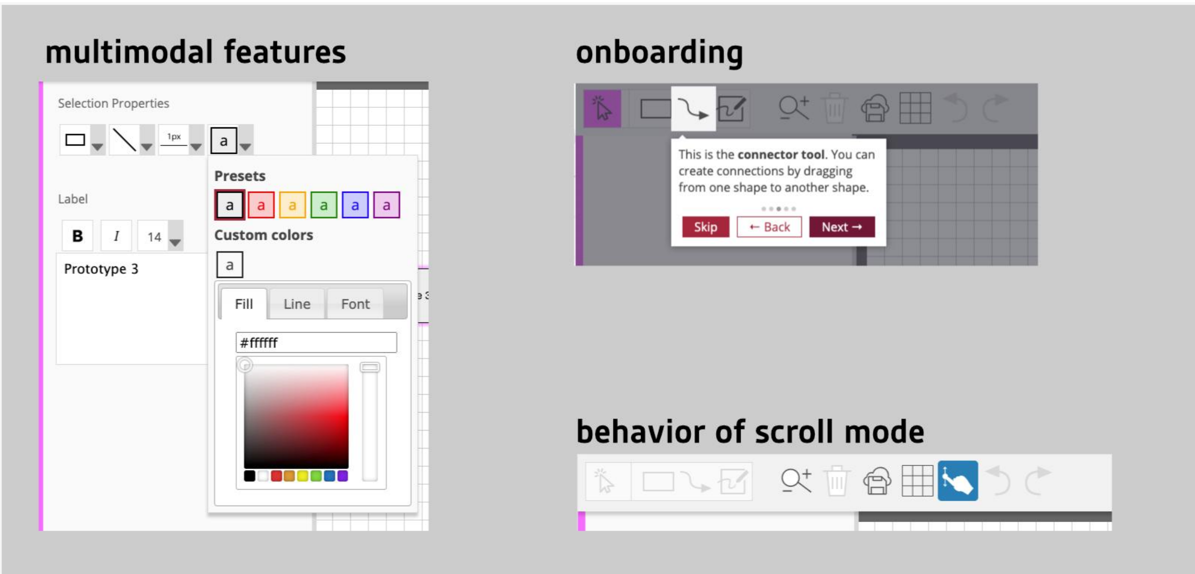
- I adapted several icons in the main menu based on participants' feedback. The "select" icon now purposefully symbolizes a "click" action with a cursor. The "zoom" icon now includes "+" and "-" indicators to prevent misinterpretations as search. The "save" icon now depicts a disk symbol and a cloud.
- I moved the buttons for "single creation mode" and "unlimited creation mode" to the sidebar to enhance discoverability and prevent accidental activation.

Fig. 44: *Overview of prototype b-1*



- I included a new set of multimodal features (Fig. 45), namely custom colors (separate for fill, line, and font color) and basic typography options (bold, italic, font size). Users can either pick one of the color presets or create a custom color scheme. The color icon now presents fill, line, and font color separately to provide a clear preview of how a preset will adapt a shape.
- I included an onboarding at the first load of the concept mapping tool to describe the functionalities. The onboarding has five steps (selection mode, concept creation mode, link creation mode, freehand drawing mode, and other functionalities for operating the canvas or document).
- I adapted the behavior of the scroll mode. When scroll mode is active, prototype b-1 disabled unavailable options, particularly the creation modes, to give a clear indication of the behavior change.

Fig. 45: *Further enhancement of prototype b-1*



8.3.2 Data Collection and Setting

I combined qualitative (think-aloud commentary and observation during interaction with prototype b-1, debriefing interview afterward) and quantitative measurements (UEQ; Laugwitz et al., 2008) of user experience. The study setting was identical to the study in Chapter 7 (see Fig. 40). The study used a low-directed, realistic concept mapping task. I asked the participant to create a concept map about the role of digital technology in learning. In specific, I provided the following instructions for the task:

> As mentioned, you will create a concept map according to your own ideas. The topic is "The role of digital technologies in learning". You can include everything in your map that is important to you, e.g., advantages, disadvantages, experiences, prerequisites… Please write all relevant topics as concepts in shapes and connect them with labelled links so that relations become clear. You may use every function of the tool.

The interaction phase with the prototype lasted 30 minutes. Participants were provided with a timer but were free to finish their concept maps afterward if they wished.

The debriefing interview followed a similar, standardized interview guide like the study in Chapter 7 but included several additional questions. First, I asked each participant to recapitulate positive and negative experiences with the concept mapping tool and comment on my notes of their behavior and think-aloud commentary. Second, I asked participants to explain their concept maps, particularly focusing on their use of multimodal features. Details about these findings are available in Chapter 12 on multimodal features in concept mapping. Third, I discussed fulfillment of psychological needs during concept mapping using the UX cards (Lallemand, 2015)[18]. I introduced participants to the cards by explaining their structure and reading aloud the definition of each psychological need in randomized ordering. Then, I asked participants which cards described their experiences during the concept mapping and discussed the reasons for their choices. Participants could refer to the definitions and examples on the UX cards at any time during the study. The participants were free to choose as many cards as they liked and could ask questions at any time. Finally, participants had the opportunity to ask additional questions about the experiment.

8.3.3 Analysis

8.3.3.1 RQ 1: Problems and Opportunities for UX Design

Regarding RQ 1, the analysis procedure was identical to study 2a. I performed a qualitative summarizing content analysis (Mayring, 2002) of the debriefing recordings. I included a severity rating from 1 to 3 and a categorization into positive and negative findings. I will concentrate on findings with a severity of 2 and 3 (like in Chapter 7, a table of all results is available in Appendix D). Furthermore, I grouped the findings whether they refer to specific functionalities ("what" the tool does) or interaction design ("how" users interact with the tool).

8.3.3.2 RQ 2: Critical Incidents in Digital Concept Mapping

Regarding RQ 2, I followed a structured procedure to identify critical incidents. I first imported the recordings of the interactions into MaxQDA. Each video contained three frames (see Fig. 39): the mirrored recording from the interaction, the participants' facial reactions and think-aloud commentaries, and the participants' actions.

Regarding users' think-aloud commentaries, I assigned codes to each so-called verbal unit, defined as a "segment of thoughts about one specific topic" (Hilbert & Renkl, 2007, p. 60). In the present chapter,

[18] A detailed discussion of the UX cards is available in Chapter 4.

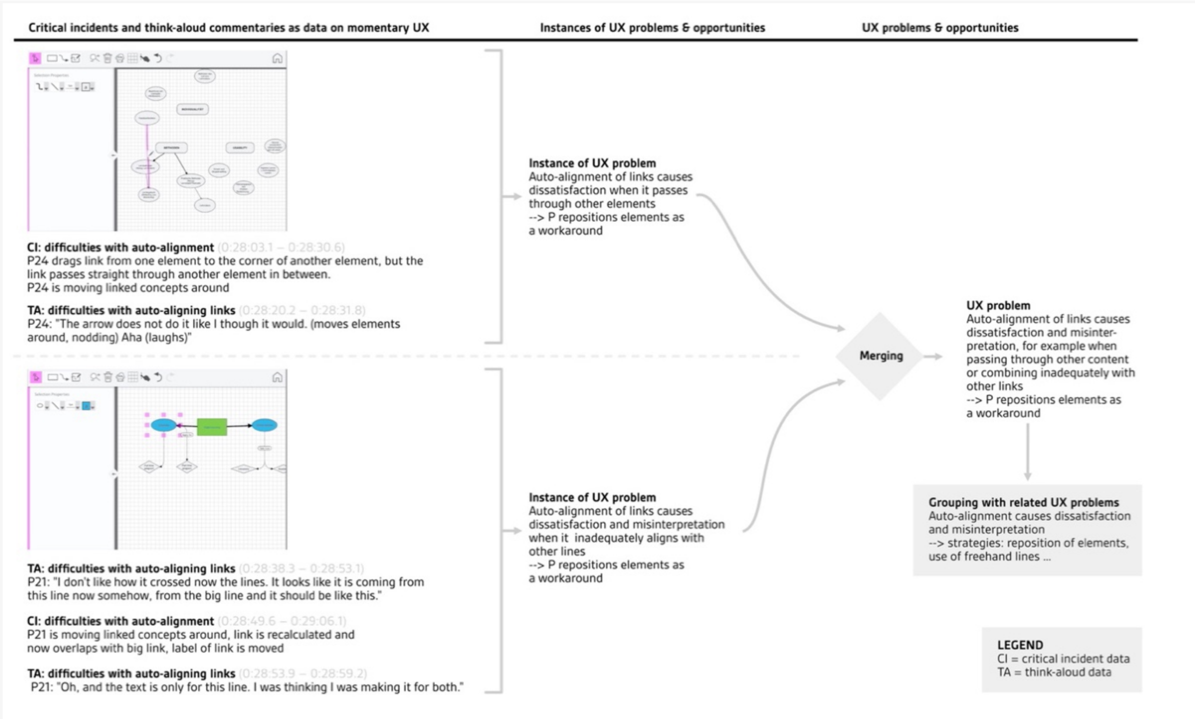
I will concentrate on think-aloud comments unrelated to the content of the created concept maps[19]. I decided to use a bottom-up, summarizing content analysis of each verbal unit (Mayring, 2002): Each verbal unit was paraphrased into a code. I then combined codes that were close in semantic meaning. Finally, I categorized codes by functionalities or actions affected, such as selecting elements, drawing shapes, or navigating the canvas.

Regarding users' behaviors, I carefully coded the interaction videos for critical incidents. I concentrated on observable behavior and reactions of users. For example, when users dragged a link to an empty area, I applied the code "linking elements causes troubles". Such an observational approach naturally involves qualitative interpretation. Consequently, I provided definitions for the critical incidents to avoid over-interpretation (see Appendix E).

For identifying UX problems and opportunities, I decided to implement a structured approach (Hartson & Pyla, 2012; Howarth et al., 2007), illustrated in Fig. 46. Using MaxQDA, I went through all codes (think-aloud and critical incidents) and combined them into instances of UX problems and opportunities (e.g., auto-aligning links causing dissatisfaction, see Fig. 46). These instances refer to each time a participant encountered a particular UX problem or opportunity (Howarth et al., 2007), for example, a problem with the auto-aligning links. Each instance could hold several coded critical incidents, and each participant could experience instances of the same UX problem or opportunity multiple times. After identifying these instances, I merged related instances into UX problems and opportunities (e.g., auto-aligning links causing dissatisfaction and misunderstandings, see Fig. 46), and grouped related findings (for example, all UX problems with auto-flowing links; Howarth et al., 2007).

[19] I coded content utterances and non-word-utterances as well but will not report on them here because they are out of scope for the design-informing character of the Chapter.

***Fig. 46**: Structured approach for converting think-aloud comments and critical incidents into UX problems and opportunities (Hartson & Pyla, 2012; Howarth et al., 2007)*



8.3.3.3 RQ 3: Psychological Needs in Digital Concept Mapping

Regarding RQ 3, I performed three analyses. First, I counted how often participants mentioned the different psychological needs to describe their experiences. Second, to identify the major reasons for each psychological need, I carefully listened to the audio recordings multiple times and performed a qualitative summarizing content analysis (Mayring, 2002). Specifically, I paraphrased each statement into a code. For example, I summarized the statement "first of all, the creation of the map makes you proud of what you have done" (P16) into the code "tool makes you proud". I assigned the same code to statements with identical meanings. Afterward, I collected all statements in a document and categorized them into the reasons identified in the results section.

8.4 Results

8.4.1 RQ 1: Problems and Opportunities for UX Design

8.4.1.1 Functionalities

Similar to the study in Chapter 7, the **auto-alignment of links** remained to cause problems (P22, P24, P25, P23: "I wanted to create something curved, but it does not curve like I wanted"), indicating that it was not an artifact of the setting. The provided **onboarding** was received positively (P26: "I liked the hints at the beginning”). Only one participant disliked it, but several others suggested making it longer or more interactive.

The additional **multimodal features** enhanced the experience. Several participants liked that they were able to choose custom colors. However, the current solution was not perfect: Participants could specify their colors with a color picker but had to activate it with an additional click. Several participants disliked this activation step: “I thought when I want a box with a particular color that takes too much time” (P22). Furthermore, several participants emphasized the need for more shapes, in particular “human shapes” (P1) or “cloud shapes“ (P1, P20, P31), and more arrows (P5, P7, P16, P18, P24, P30) like lines with multiple targets, undirected lines, or bidirectional lines. Further suggestions were the inclusion of images or videos (P1, P19), providing adaptable templates (P31), and note-taking functionalities (P11, P19).

8.4.1.2 Interaction Design

The distinction between **single and unlimited creation modes** caused fewer difficulties than in the previous study (Chapter 7). In particular, the problem of accidentally activating unlimited creation mode was less frequent (but not completely resolved). However, participants rarely used it, casting doubts on its usefulness.

The problems caused by misunderstanding **icons** were largely solved in the current design iteration, and some participants suggested adding labels to the menu to enhance clarity further. The biggest remaining problem was the selection mode. While participants generally understood it, the association with a mouse cursor remained unfamiliar on the tablets.

The problem of **creating links** was less pronounced in this study than in the previous study (Chapter 7). Some participants indicated that it took some time to learn how to drag links from one concept to another, but the onboarding solved the most serious difficulties. However, several participants expressed being unsure about how to **write labels on links and concepts** and had difficulties finding the edit buttons on the elements.

Overall, the interaction design problems on **tablets** were less severe but not solved in this study. Deactivating non-usable functionalities in **scroll mode** (see Fig. 45) gave participants a clear indication that the mode interprets their input differently. However, several participants still struggled to remember to switch scroll mode off (P13: “I think for me it was the most difficult problem with this button, because it forced me, I pressed it, and then I did not know how to get back to the main functions.”). **Zoom mode** was also not frequently discovered. In summary, the evidence suggests that participants do not easily understand the modes for scrolling and zooming. Gesture support was frequently suggested as an alternative.

The **freehand drawing functionality** again played an interesting role. It was generally perceived very positively (P15: “I like this option, it is like Paint, if I want to create a special sign, it is something good if I want”). However, several participants preferred regular shapes, often suggesting shape recognition

(P30: “you could see that I have made it myself, it did not turn into something orderly”). Furthermore, freehand should also support drawing lines and notes without filling them (P5: “I had the hope that I can draw a line. You can kind of draw a line, but then I realized that the whole purpose is to fill a box”). A follow-up design iteration could enable this option to enhance the flexibility of the freehand drawing functionality.

8.4.2 RQ 2: Momentary User Experience in Digital Concept Mapping

Research question 2 (RQ 2) investigated momentary user experience using a combination of critical incidents and think-aloud. In general, findings from RQ 2 support findings from RQ 1, but contribute to a clearer picture of user experience. I identified three main findings: investigating the importance of findings, identifying new insights, and investigating the role of the freehand drawing tool. A full table of the results is available in Appendix F.

8.4.2.1 Investigating the Importance of Findings with Momentary Experiences

Evidence from the analysis of momentary user experience indicates that several findings might be more important than data from other methods suggests. Three examples were particularly frequent. First, the most prominent example was selecting elements. I identified 177 instances of this UX problem (30 of 31 participants) where users tapped on an element without activating the selection mode, often resulting in the unintended creation of elements on top of other elements when unlimited creation mode was active. 28 of the 30 participants learned later how selection mode works (the two others avoided selecting elements, for example, by undoing accidentally created concepts and handwriting), and only six participants mentioned selection issues in the debriefing interviews. However, the frequency of selection problems indicates that users expect to select elements by tapping on them, independent of a particular mode.

Second, several findings concern the linking functionality. Despite the onboarding, around ⅔ of participants (71 instances) were uncertain about creating links in the beginning (e.g., dragging a link to an empty area). However, almost all (19 of 20) found the solution, sometimes trying the freehand tool as a workaround (5 participants, including one who did not find another solution). Likewise, 28 participants (72 instances) attempted to adapt the flow of auto-aligning links, in particular when they crossed other elements. Auto-aligning links also created misunderstandings, for example, when participants thought that labels on overlapping links apply for both links (P21: “Oh, and the text is only for this line. I was thinking I was making it for both.”). These misunderstandings could create difficulties in concept-map-based assessment because some scoring methods award less credit to unlabeled links. Participants had several strategies to address problems with the auto-aligning links, such as repositioning elements (23 instances) or deleting and recreating links with other options (21 instances). Only six participants (6 instances) accepted the flow of links, even if it did not match their intentions.

Third, canvas interactions remained problematic. 22 of 31 participants attempted to use multitouch gestures to interact with the canvas, mirroring their frequent mentioning during the debriefing interviews. Evidence suggests it is questionable whether the dedicated "scroll" and "zoom modes" are acceptable alternatives: About half of the participants experienced problems concerning the scroll mode. Despite the visual deactivation of unavailable functionalities, they still tried to create elements when scroll mode was turned on. All of these participants were eventually able to deactivate the scroll mode again but often expressed frustration (P13, after struggling with scroll mode for about three minutes: "What a stupid button! Jesus!"). Instead of scrolling, some participants closed the sidebar to have more space, but this sometimes caused problems finding the options in the sidebar.

8.4.2.2 Discovering new Insights With Data on Momentary Experiences

The critical incident technique also revealed insights that were not discovered with other methods. For example, the pink preview line that users drag between concepts always represents a straight, direct connection, but the default link style is a curved connection. The non-matching of preview and result was often confusing (P12: "I do not know why it creates some line that instead of going directly passes through the center […]. And for me it is not really interactive if the tool does not listen to what I want to make."). Several participants tried to draw a connection several times because they had not realized it was already created. Other examples of new insights were

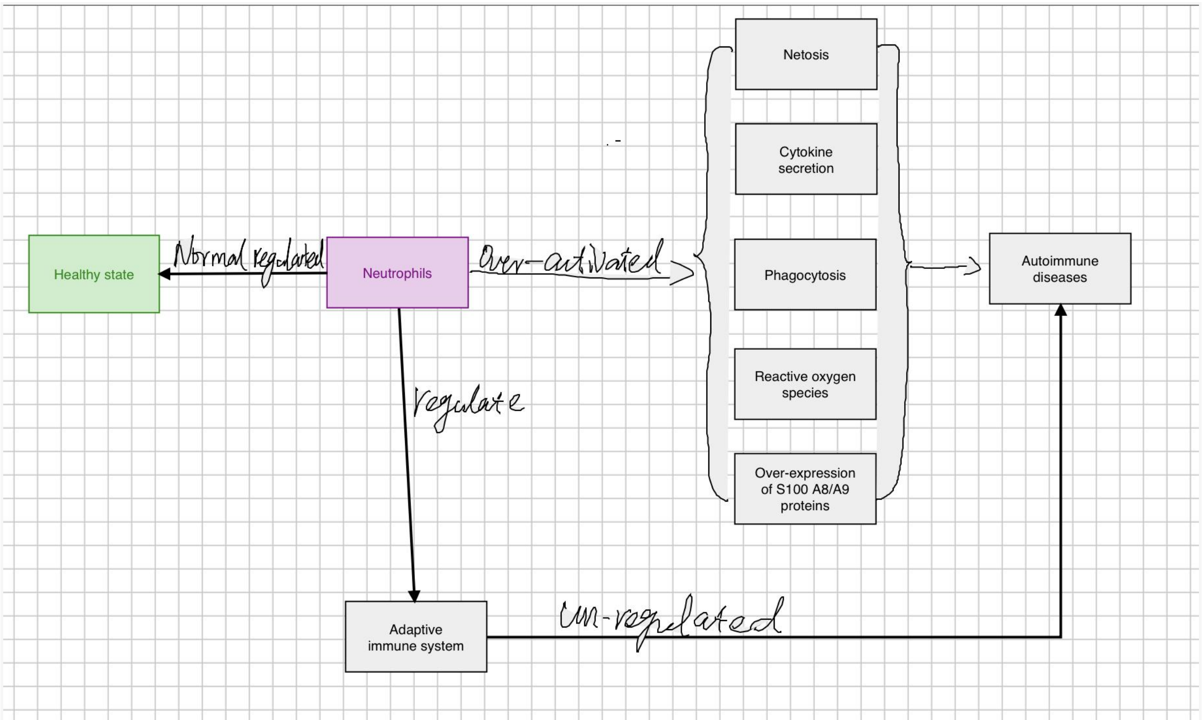
- bugs (eight participants),
- closing the document with the "home" button (six participants), and
- accidentally creating new elements when participants tried to perform gestures or missed a user interface target (seven participants).

Finally, analysis of momentary experiences revealed that some optimizations could cause unconsidered side effects, particularly the color preview symbol (Fig. 45). I intentionally created it to provide a simultaneous preview of line, fill, and font color, but four participants misunderstood it to refer to labeling information and started to write content into the custom color field. Interestingly, participants rarely addressed these problems in debriefing or were relatively unspecific when I asked them about them (P2, when a bug opened a new document in a new browser window: "And I thought I created some maps and deleted them by accident."). Potentially, these problems were not fully understandable for participants, and therefore, they might not be reporting on it in debriefing.

8.4.2.3 Insights Into the Role of the Freehand Drawing Tool

Finally, analysis of momentary user experience revealed interesting findings of the role of the freehand drawing tool. Only four participants used it as intended to create custom shapes or annotate elements when features are not available (Fig. 47). However, for most users, the freehand drawing tool became a solution whenever they experienced a problem that they could not solve. For example, nine participants used the freehand tool to write by hand, often because they did not understand how to activate elements to write into them (Fig. 47). For some participants, this workaround created expectations of a more paper-like interaction, for example, crossing out elements to delete them (P4) or searching an eraser tool (P12). Freehand elements also caused problems when participants repositioned elements on the canvas: Unlike regular labels, freehand writings do not move with the links and concepts they were supposed to describe.

Fig. 47: *Use of freehand drawing to group elements for being able to connect them with a single link and for writing on links when the link labeling function was not discovered (P14)*



8.4.3 RQ 3: Psychological Needs in Digital Concept Mapping

Table 10 presents how often participants mentioned different psychological needs to describe their concept mapping experience, together with their main reasons.

Table 10: *Number of mentions and reasons for psychological needs (N = 31)*

Need	Mentions	Reasons
competence & effectiveness	23	(1) understanding structural relations (2) enhanced effectiveness of learning (3) achieving feelings of confidence
autonomy & independence	15	(1) being autonomous in concept map creation (2) creativity and active learning
pleasure & stimulation	9	(1) stimulation and motivation during concept mapping (2) absence of UX issues (3) creative self-expression

self-actualizing & meaning	9	(1) relating personally to the topic of concept mapping (2) active learning with long-term, continuous improvement
security & control	6	(1) feeling in control of the interaction with the tool
influence & popularity	2	(1) using the tool in teaching situations for influencing students
relatedness & belongingness	1	(1) semantic relations

8.4.3.1 Competence and Effectiveness

The need for competence and effectiveness was the most frequent, mainly providing three reasons. First, participants emphasized that concept mapping helps to understand structural relations (P10: "this tool helps you structure everything and you have to put it somewhere where it has to go […] in this way you get competence and effectiveness"). Second, participants expressed that concept mapping enhances learning effectiveness, either for oneself (P4: "I maximize my time […] When you learn, to really know what you know, you have to tell it to someone else. But I also do concept maps for myself because it is like explaining it to someone else.") or for others (P30: "I wanted to create it well because you want to make it effective, so that it is clear and understandable"). Third, several participants expressed that fulfilling the need for competence and effectiveness results in feelings of confidence and pride (P16: "the creation of this map makes you proud of what you have done"). Several of these findings are in line with desired outcomes of participants expressed in the studies in Chapters 2 and 3, particularly the benefits for learning and seeing semantic relations of a topic.

8.4.3.2 Autonomy and Independence

About half of the participants associated their experience with the need for autonomy and independence. A central reason was being able to create concept maps autonomously, often by relating to an easy-to-use design that lowers the need for training (P14: "when I used this tool, I felt it is not so difficult to use, it is very easy to learn, just by click click you do not need to read a lot of documents"). The need for autonomy and independence was also connected to creativity and active learning. Concept mapping could "help me to have an independent look of the subject and the topic" (P15) and allow "including what you want […] there was no right or wrong" (P9). Participants thought that this creative freedom is related to innovative results because "when it is independent, people get a free environment for what to do […] then the better things come out, I mean the innovation and creativity comes out" (P1).

8.4.3.3 Pleasure and Stimulation

Nine of 31 participants associated their concept mapping experience with pleasure and stimulation, with three main reasons. First, participants referred to feeling motivated by the concept mapping because "you are imitating something from your mind and trying to release it" (P20). This finding supports participants' suggestions described in Chapter 3 where numerous stories examined how concept mapping could engage and motivate learners. Participants often referred to being completely immersed in the activity, for example, P24 ("I could have done it for another half an hour […] because I felt pleasure and was stimulated to immerse myself more into it."). Such stimulating experiences resemble the concept of flow (Csikszentmihalyi, 2008). Second, participants expressed a relation of user experience to fulfillment of the needs for pleasure and stimulation. It can harm (P13: "there was no pleasure at all" and that "your creativeness was killed within this") or favor fulfillment of the need for pleasure and stimulation (P19: "I use so many software as an engineer […] this was the first time I did not feel stress or something, it was so easy"). Third, functionalities that allow users to express themselves creatively were often associated with fulfillment of the need for pleasure and stimulation, in particular the use of multimodal features (P15: "Pleasure because it is something beautiful, something creative. It is not just right but it has different colors to help you memorize better.").

8.4.3.4 Self-actualizing and Meaning

Nine participants associated their concept mapping experience with the need for self-actualizing and meaning, mainly associated with relating personally to the topic of concept mapping (supporting findings described in Chapter 3 where participants emphasized that learners have to see the personal value of concept mapping). Participants also related self-actualizing to active learning (P7: "you create it yourself, it is not a readymade presentation you take from your teacher […] it is like preparation without anyone helping you.") that ultimately leads to long-term continuous improvement, closely related to the need for competence and effectiveness (P8: "it is when you improve yourself and you update your knowledge, you get more competence and feel more confident when you have more competence and knowledge").

8.4.3.5 Security and Control

Six of 31 participants referred to the need for security and control for describing their concept mapping experience, mainly associated with feeling in control of the interaction. Participants who experienced user experience problems tended to feel restricted by the tool (P5), and participants who did not experience such problems tended to "feel it is totally in your control what you are doing, you have a feeling that it is going well" (P6).

8.4.3.6 Social Needs

Finally, social needs played a minor role in the concept mapping experiences. Two participants referred to the need for influence and popularity but associated it with using the tool in teaching situations. Such situations were experienced as influencing students. P10 referred to the need for relatedness and belongingness in terms of semantic relations by "seeing how you match all the things helps you see the whole picture, like everything fits together", but was unsure about this association. This statement mirrors findings from the study in Chapter 4 about a misinterpretation of relatedness in terms of semantic relations instead of social relatedness.

8.4.3.7 Investigating the Relation of UX Design to Psychological Needs

Furthermore, the results support several hypotheses regarding user experience and psychological needs derived in Chapter 4:

- I hypothesized that pragmatic user experience might be associated with feeling in control of the interaction, mainly concerning the need for security and control (Hassenzahl et al., 2010). The results largely support this hypothesis. Several users said that problems during the interaction with the concept mapping tool reduced their feelings of control.
- Support is also provided for my hypothesis that the hedonic dimension of user experience might be mainly related to fulfillment of pleasure and stimulation. Users often mentioned stimulating functionalities like multimodal features (P27: "I really liked the colors and the shapes and everything"). Pleasure was also associated with feelings of confidence and pride when users successfully expressed their knowledge and ideas in a concept map (P16: "the pleasure you get from creating these kinds of things, when you finish, you get proud of what you have done").
- I hypothesized that eudaimonic user experiences might be associated with fulfillment of competence/effectiveness and self-actualizing/meaning. The analysis of momentary user experiences revealed that problems in user experience were experienced as interrupting the cognitive flow of users, as they frequently switched from speaking about content aspects to addressing problems in interaction. Thus, users need an easy-to-use concept mapping tool as a prerequisite for realizing their potential with concept mapping. Such a tool allows users to concentrate on the concept map itself, but user experience problems interrupt these processes and shift attention to the interaction itself (P5: "at some point I was thinking about how to make the map and sometimes thinking about the effectiveness of the map"). Fulfilling these needs creates confidence and, ultimately, pleasure.
- Finally, I hypothesized that pragmatic and eudaimonic user experience might be related to fulfillment of autonomy and independence. My results are largely in line with this hypothesis. Pragmatic enhancements like an easy-to-use design and the onboarding supported users in feeling autonomous in concept map creation, potentially reducing the impact of individual competencies like Information and Communication Technology Literacy (ICT; Katz & Macklin, 2013). The low-directed concept mapping task supported fulfillment of autonomy and independence further. I propose investigating it in other concept mapping tasks to verify whether this relation of concept mapping and autonomy is an artifact of my particular setting.

8.5 Discussion

8.5.1 Triangulation of Several Methods to Investigate Momentary and Episodic User Experience

Although methodological considerations were not the main purpose of the present study, the results indicate how a triangulation of data from think-aloud comments, observation of critical incidents, and debriefing contributes to getting a complete picture of user experience. The data about momentary experiences (Roto et al., 2010), namely think-aloud comments and critical incidents, allowed investigating the severity of identified problems and design opportunities. Furthermore, it revealed findings that other methods did not uncover, for example, bugs that the participants could not adequately describe, and created insights into the role of the freehand drawing functionality. Data on episodic user experience (Roto et al., 2010) from debriefing and UX cards (Lallemand, 2015) allowed to acquire insights about how the design of a digital concept mapping tool shapes user experience.

8.5.2 Enhancing UX in a Follow-up Design Iteration

RQs 1 and 2 contributed to defining areas for enhancing UX in follow-up design iterations. Fig. 48 summarizes the key design-related findings from this study. A follow-up prototype c-1 (see Fig. 49) was created to address these findings. Observation of momentary user experience revealed that users often did not switch to selection mode to select elements but typically had little problems understanding the behavior in debriefing. I added labels to the menu and hypothesized that these might ease the understanding of the dedicated selection mode. I also removed the single creation mode to avoid changes in the behavior of selecting and creating elements: participants can create elements when clicking in creation mode and select elements when clicking in selection mode. I set the default setting of link lines to "straight" to address problems deriving from differences between the purple preview and the resulting line. The sidebar of prototype c-1 has dedicated color pickers for line, fill, and font color. Each color picker has a suggested palette of colors, automatically saves custom colors for later use, and includes the option to specify the opacity of colors. I hypothesized that these changes address the problems of switching to a custom color preset and misinterpreting the color preview icon as text input. The color picker now allows transparent fill colors, enhancing the flexibility of the freehand drawing feature: Users can set a transparent fill color and use freehand lines or handwriting without automatically closing the shapes with a fill color. Finally, I enhanced the visibility of the text fields for labels and the typography options. In prototype c-1, they are visible as soon as an element is selected, without the need to click on a dedicated "edit label" button. Furthermore, I enabled closing the onscreen keyboard by tapping outside of the canvas (in addition to the provided buttons on the keyboard itself).

***Fig. 48**: Overview of key findings from the study in Chapter 8 and enhancements in prototype c-1 (Chapter 11)*

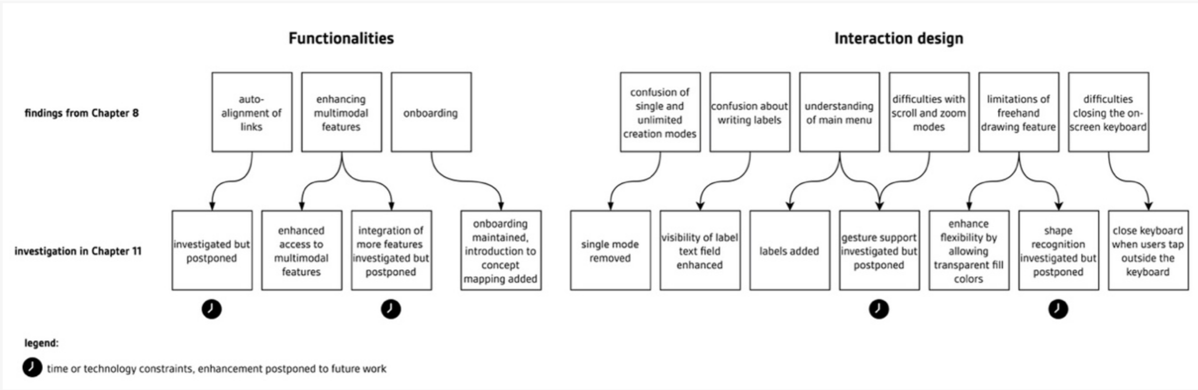
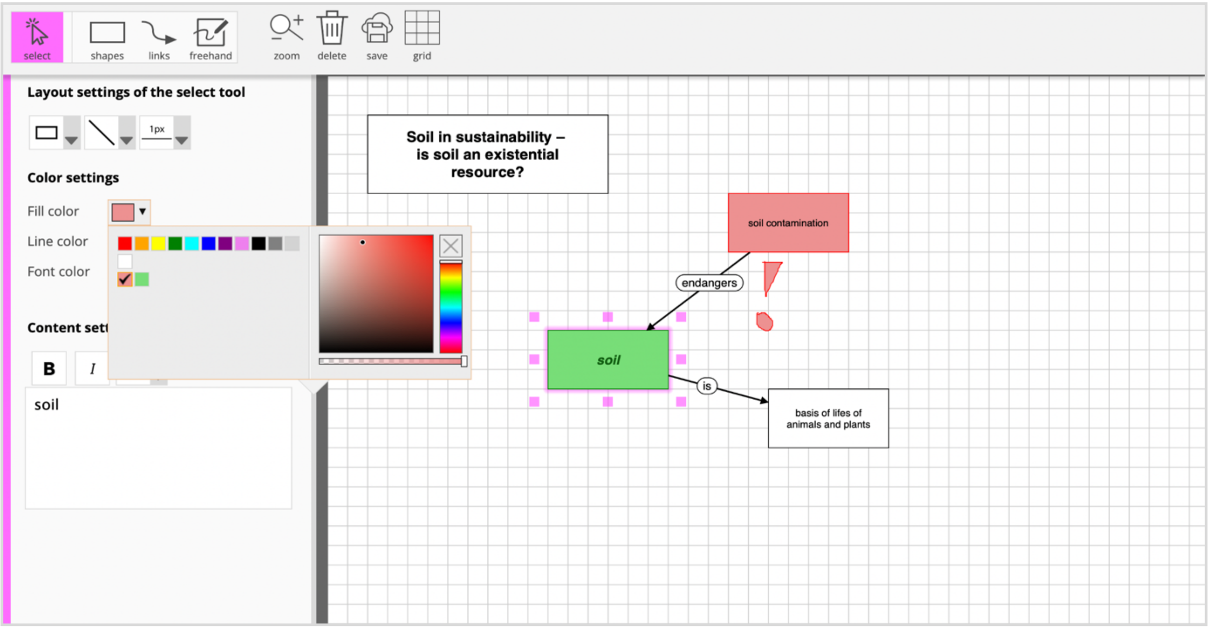


***Fig. 49**: Prototype c-1 after optimization for the study in Chapter 11*



While this prototype addresses many of the key findings described in this chapter, I could not implement all feedback in the given technology and time constraints. I verified the technological basis of the prototype, a JavaScript vector framework called Raphael.js[20], to investigate options for implementing more shapes and line types or adapting the flow of link lines. Unfortunately, all of these ideas would require manual implementation with custom code. I also investigated the use of gesture frameworks like Hammer.js[21] to support gesture navigation (in particular, pinch-spread gestures to zoom and two-finger swipes to scroll). I was able to create a promising first version that registers the number of fingers and their movements and performs different actions, but unfortunately, there were cases where the prototype's coding would interfere with the coding of Hammer.js. In these cases, canvas gestures would

[20] The documentation of Raphael.js is available at https://dmitrybaranovskiy.github.io/raphael/.

[21] The documentation of hammer.js is available at https://hammerjs.github.io/.

be misinterpreted as drawing gestures or vice versa. Technology and time constraints made it impossible to advance prototyping in these directions, in particular because coding is not the core task of the present dissertation, and one of the key objectives of development was to keep the technological basis close to the prototype described by Weinerth (2015). Furthermore, several other questions remained open for a thorough user experience evaluation of the prototypes: Thus far, I had tested the prototypes in qualitative lab studies and without exploring assessment conditions.

As a consequence of these challenges, I performed pre-tests of the prototype and finally decided to evaluate it in a quantitative setting under high ecological validity, postponing potential further enhancements to future work. In Chapter 11, I compared prototypes a-1 (from the study in Chapter 7) and c-1 (after implementing feedback from this study)[22]. A detailed description of the results is available in Chapter 11. In short, participants' feedback indicates that issues identified throughout the user tests did not appear again for the final prototype, indicating that the overall design quality has again been enhanced.

8.5.3 Towards a Psychological Needs Profile for Concept Mapping

RQ 3 contributes to the development of a psychological needs profile (Desmet & Fokkinga, 2020) for concept mapping. Overall, the results support findings from the study in Chapter 4. However, the present study was based on a real concept mapping experience and investigates how the design of a digital concept mapping tool impacts the fulfillment of psychological needs.

Fig. 50*: Comparison of findings on psychological needs from Chapters 4 and 8*

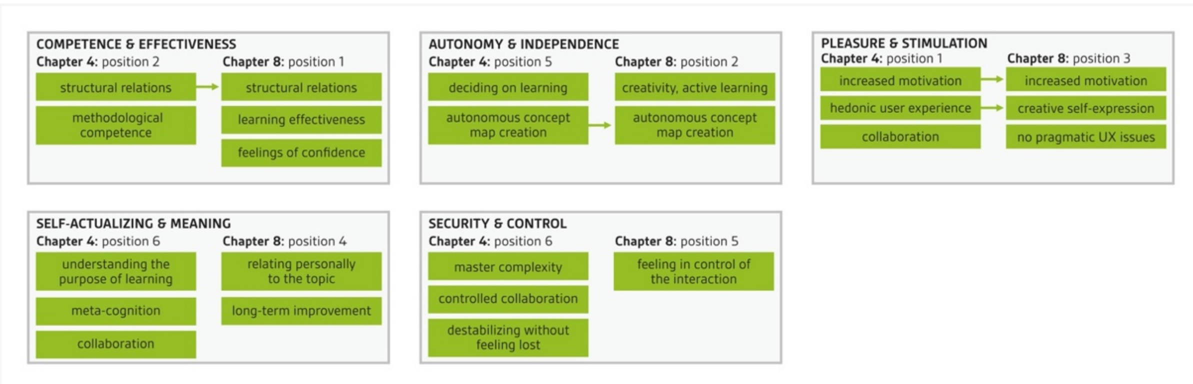


Fig. 50 compares the findings from the studies in Chapters 4 and 8, along with the identified reasons. Reasons supported by both studies are visualized with arrows. The social needs (relatedness &

[22] One additional change was implemented between the studies: I removed undoing and redoing. Discussions with the development team had revealed that implementing such functionality into OASYS might be difficult. Thus, I wanted to know how user experience changes without this functionality to discover whether the development effort is worth investing. Results clearly indicate that users expect an undoing and redoing functionality.

belongingness and influence & popularity) are not included, given their minor role in the present study. In the following, I will compare the findings in detail:

- **Competence and effectiveness**: Participants in both studies emphasized that the concept mapping tool can help understand structural relations. Participants did not refer to acquiring methodological competence for effective concept mapping in the present study, presumably due to the shortness of their experience with the concept mapping tool. However, they identified increased learning effectiveness and feeling confident as additional factors for competence and effectiveness.
- **Autonomy and independence**: Both studies revealed autonomous concept map creation as a major reason for the fulfillment of autonomy and independence. However, participants emphasized autonomy much more strongly in this study, indicating that the need has a strong influence on momentary user experience in digital concept mapping. An easy-to-use tool design can support feelings of autonomous creation of concept maps. Furthermore, participants identified active learning as a reason for fulfillment of the need for autonomy and independence.
- **Pleasure and stimulation:** Evidence from both studies supports the relation of fulfillment of the need for pleasure and stimulation to motivation. I hypothesized that multimodal features could contribute to such need fulfillment because they allow users to express their creativity. In support of this hypothesis, several participants mentioned creative self-expression as a source of pleasure, related to aspects of hedonic user experience like pleasing aesthetics (identified in the study in Chapter 4). However, I also discovered some issues with multimodal features in the tested prototype (particularly, limitations to functionalities and problems applying multimodal options). These might explain why the need for pleasure and stimulation was mentioned less frequently in the present study than in Chapter 4, indicating the requirement to enhance the hedonic dimension of UX further.
- **Self-actualizing and meaning:** Participants in the study in Chapter 4 emphasized that fulfillment of self-actualizing and meaning is associated with understanding the purpose of learning. The present study identified relating personally to the topic of concept mapping and long-term continuous improvement as related to the fulfillment of the need for self-actualizing and meaning.
- **Security and control:** The need for security and control was associated with feeling in control of the interaction with the concept mapping tool, not with the associations of mastering complexity, controlling collaboration, and destabilizing from the study in Chapter 4. These associations are likely to derive from the concept mapping setting, which did not involve acquiring new knowledge.
- Similar to the study in Chapter 4, the social needs were not important in this study, in line with the individual concept mapping setting.

Although these results are encouraging, they are still exploratory: I engaged participants in a deep qualitative discussion about need fulfillment, but I did not measure need fulfillment systematically. Consequently, I cannot quantify the relations of need fulfillment and user experience. A follow-up study could investigate need fulfillment systematically, for example, with the help of a questionnaire (Lallemand & Koenig, 2017), and explore its relation to user experience (see Chapter 11).

8.5.4 Limitations

A limitation to my observational approach of identifying critical incidents is that it involves interpretation. Although I paid close attention to follow a structured approach to mitigating the "evaluator effect" (Hertzum & Jacobsen, 2001; Howarth et al., 2007) as outlined in the analysis section, I cannot rule out that other observers might identify other critical incidents. As a consequence, I took care to triangulate findings from my critical incidents technique with other data sources, covering both momentary (think-aloud commentary) and episodic user experience (debriefing interviews, UEQ; Roto et al., 2010). Although this triangulation makes me confident of the quality of my results, I think that a double-coding of critical incidents might serve as a further validity check.

9 General Discussion: UX Design for Concept Mapping

The present chapter has outlined a human-centered UX design approach to a digital concept mapping tool (see Chapter 1). Building on prior work by Katja Weinerth (2015) and Eric François, three design iterations of the prototype were created and evaluated. The studies contributed several enhancements:

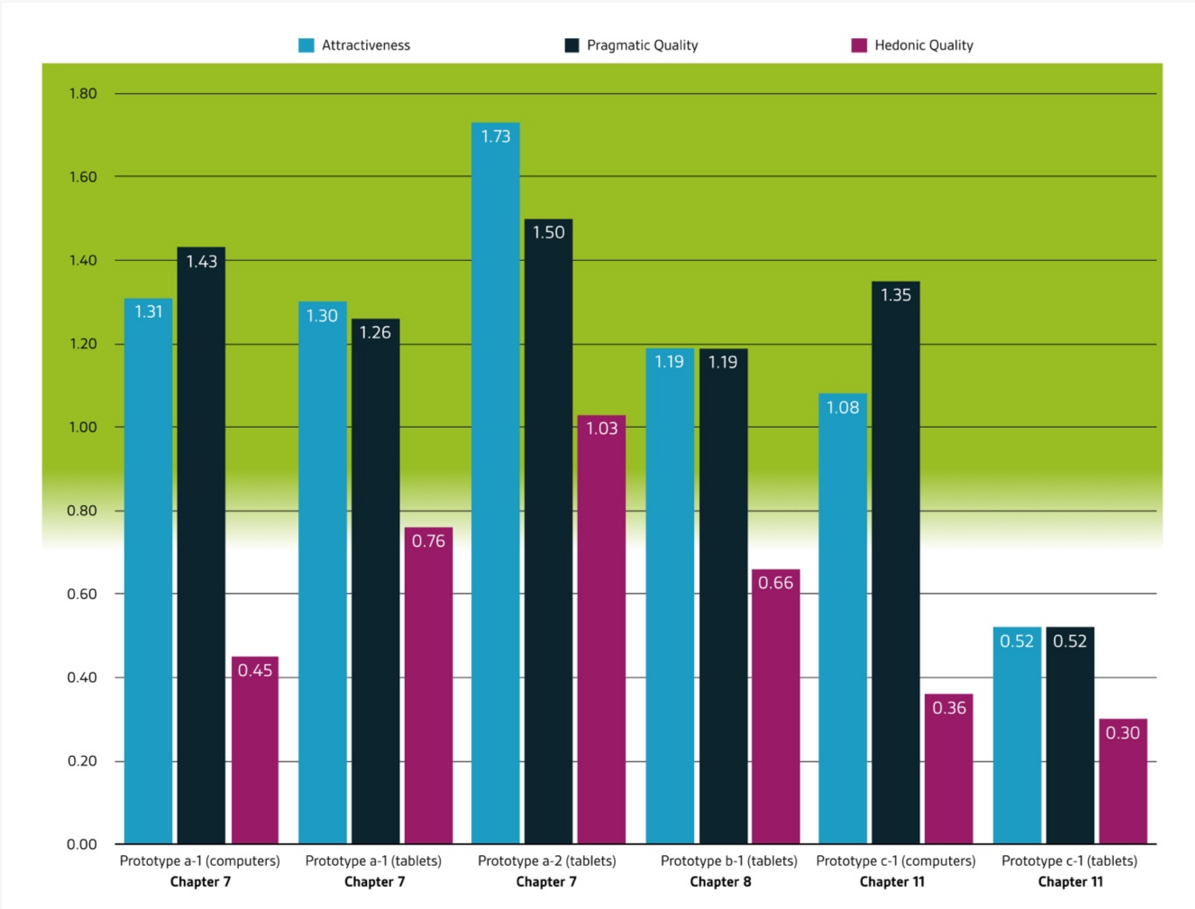
- solving the confusion deriving from the single and unlimited creation of elements,
- providing an onboarding,
- making the input text area visible when an element is selected (instead of requiring an explicit click on an "edit" button),
- enhancing the menu by adding labels, refining icons, and visually deactivating actions that are unavailable in a particular mode (e.g., the scroll mode),
- enhancing multimodal features by adding custom coloring and typography options,
- setting link line options to "straight" (instead of curved lines) to align the purple preview (visible while dragging a new line).

9.1 UEQ Comparison of Prototypes

Besides the qualitative feedback on the design iterations, the UEQ (Laugwitz et al., 2008) was administered for acquiring insights into a quantitative evaluation of user experience (Fig. 51). UEQ measures pragmatic and hedonic quality of user experience and attractiveness as an overall judgment (Hassenzahl, 2001; Laugwitz et al., 2008). As a general guideline, UEQ suggests interpreting values below -0.8 as negative, values from -0.8 to 0.8 as neutral, and values above 0.8 as positive evaluations (indicated by the green gradient in Fig. 51):

- Prototype a-1 (Chapter 7) reaches the positive area for attractiveness and pragmatic quality, and the neutral area for hedonic quality, on both computers and tablets.
- Prototype a-2 (Chapter 7) reaches the positive area for all dimensions. These findings indicate that a freehand drawing functionality for concept maps is promising for enhancing the hedonic quality on tablets, although qualitative results indicate that further work is needed for implementing shape recognition.
- Prototype b-1 (Chapter 8) reaches the positive area for attractiveness and pragmatic quality. Hedonic quality is in the upper area of the neutral level.
- Prototype c-1 (Chapter 11) reaches the positive level for attractiveness and pragmatic quality on computers. Hedonic quality on computers is on the neutral level. On tablets, all scales are on the neutral level.

Fig. 51*: UEQ values of the different design iterations*



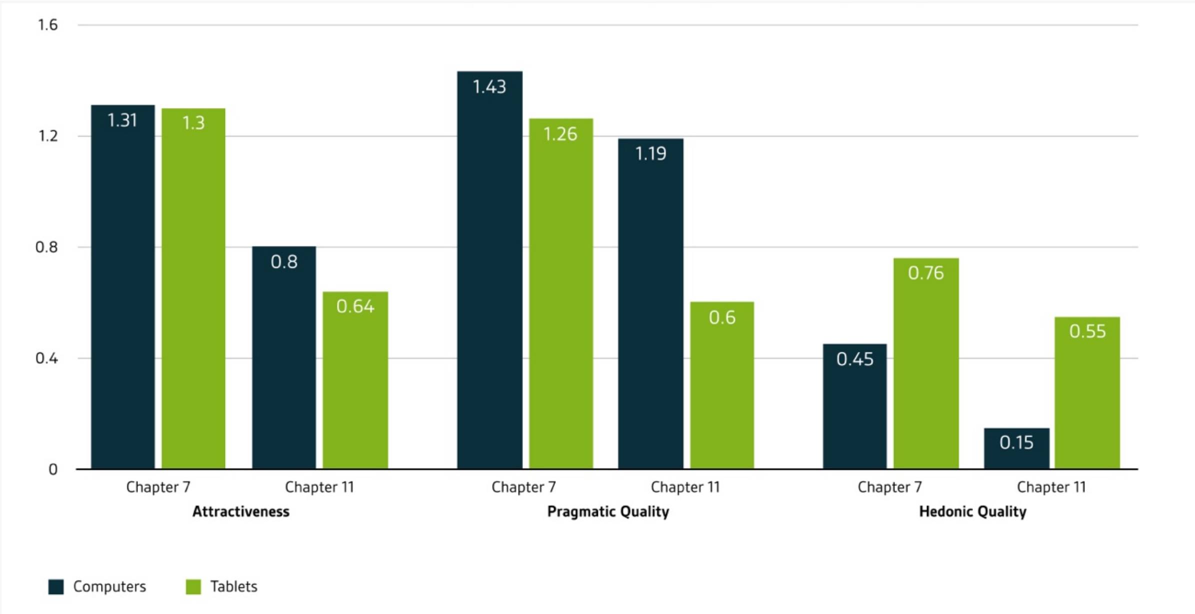
These findings reveal several interesting patterns. First, they suggest that overall attractiveness and pragmatic quality are relatively high. Hedonic quality is mostly in the upper areas of the neutral level. These values are encouraging given that they refer to prototypes created in rapid design iterations, not finished products. Second, the prototypes score higher on computers than on tablets, mirroring the qualitative findings regarding the need for touchscreen optimizations. Third, UEQ values go down from Chapter 7 to Chapter 8 and further down to Chapter 11, although qualitative feedback indicated that prototypes improved. How to explain this trend? The studies adapted the prototypes and the contextual factors like the setting (lab or classroom) and the task (lower or higher ecological validity, less or more controlled). These were conscious decisions to investigate user experience from diverse angles, but they reduce comparability across the studies. Both prototypes and contextual factors might have contributed to the changes in UEQ:

- Triangulation of different data sources, particularly the qualitative feedback, suggests that the influence from prototypes is likely not the main factor: The changes were generally judged favorably, and participants tended not to suggest reverting changes. The only systematic exception was removing the undo and redo functionality in Chapter 11: Numerous participants expressed that such a functionality is needed, despite the technological challenges it might have. This interpretation is supported by comparing prototype a-1 in Chapters 7 and 11 (see Fig. 52).

It was evaluated much better in Chapter 7 than in Chapter 11 (where undo and redo were removed). These results emphasize the necessity to have an undo and redo functionality, as these are supporting feelings of control (Nielsen, 1994).

- User experience has long emphasized the role of context and suggested investigation in a realistic setting (Roto et al., 2010). The results from the studies in Chapters 7, 8, and 11 support this suggestion. Potentially, the increasing complexity in the setting impacted the evaluations of user experience. The studies moved from purely recreating concept maps (Chapter 7) over freely expressing what one thinks about a topic (Chapter 8) to answering a specific focus question with suggested terms (Chapter 11).

Fig. 52: *UEQ evaluations of the prototype a-1 in Chapters 7 (recreating concept maps; with undo and redo) and 11 (concept mapping with focus question; without undo and redo)*



Two implications derive from these observations for a human-centered UX design process. First, building a clear understanding of the contexts of use for a to-be-developed tool is critical, as illustrated in the contextual research in Chapter 3. Second, user experience testing should cover diverse settings to establish a proper UX evaluation. The present dissertation contributes to a realistic picture of UX in digital concept mapping by exploring different contextual settings, for example, a medium-directed concept mapping task (Chapter 11) and a low-directed concept mapping task (Chapter 8).

On the other hand, the changes in setting lower the comparability of the different prototypes. Such a comparison was of lower importance in the present chapter because its main purpose was a formative assessment of user experience to identify enhancements (Hartson & Pyla, 2018; Scriven, 1967). The impact of contextual factors on UEQ supports the importance of these enhancements: When UEQ evaluations go down as complexity increases (even if the prototypes themselves are enhanced), this tendency suggests that an even better user experience is needed in realistic settings than in artificial test situations. However, when the main purpose of the investigation is to compare prototypes quantitatively, contextual factors need to be as identical as possible.

9.2 Design Recommendations

Based on the above-mentioned studies, six design recommendations can be derived for future design iterations.

9.2.1 Reducing Complexity Without Ignoring the Meaningful

Several findings indicate that users require (a) a reduced, easy-to-use interface and (b) multiple functionalities beyond the basic set. These findings are difficult to align: an easy-to-use, intuitive user interface should purposefully reduce complexity, but at the same time, participants in all studies suggested additional functionalities, each of which requires some form of user interface component.

The phenomenon of adding more and more features is often described with pejorative terms like "feature bloat" (McGrenere, 2000) or "feature creep" (Lee & Lee, 2015), suggesting that the additional features are rarely used (McGrenere, 2000) and increase complexity (Lee & Lee, 2015). Much research in HCI has focused on strategies to address complexity in design (Janlert & Stolterman, 2010; Lee & Lee, 2015). The design studies described in Part III support reducing complexity for creating positive concept mapping experiences. At the same time, users rarely suggested removing features, in line with previous research (McGrenere, 2000)[23], and often suggested additional features to make the product more versatile and complete (Lee & Lee, 2015). User experience allows an alternative view on feature creep beyond the question of complexity: With its focus on "be-goals" (Hassenzahl, 2010) like building competence, features are not only increasing complexity but also turn into resources for the personal growth of learners (Hassenzahl, 2010), promises of becoming better.

Potential future design iterations should pay thorough attention to this balance (Olsen & Malizia, 2012): How can designers aim for simplicity without depriving users of features they need for integrating concept mapping in their learning and assessment activities? The designer John Maeda (2006, p. 89) has described this line of thinking in his principle that "[s]implicity is about subtracting the obvious, and adding the meaningful".

9.2.2 Interaction Design on Tablets

The design was driven by the idea of developing a flexible tool that users could use for touchscreen-based interaction and interaction based on keyboard and mouse alike (Weinerth et al., 2014b). Support for this decision was found in the studies in Chapter 2 and 4, which revealed no clear preference for

[23] A notable exception to this finding were the numerous suggestions to remove the mode switching between creating one element and creating multiple elements.

any device. However, the studies also revealed substantial differences between computers and tablets regarding associations and interaction design preferences. Computers were mainly associated with pragmatic aspects like efficiency, ease of use, and precision. Tablets were also associated with advantages of touchscreen-based interaction (Haßler et al., 2016). Numerous associations had a hedonic aspect, especially the strong emotional connection to drawing on touchscreens with a stylus or a finger. These hedonic aspects are in line with research on emotions in tablet use, for example, on joyful interactions (Hwang et al., 2012).

A consequence is that designing a positive user experience follows different rules on computers than on tablets. For example, while users on computers readily accepted the dedicated button for zooming, almost all users on tablets strongly preferred gestures like pinch-and-spread (to zoom) or panning (to scroll the canvas). Zooming and scrolling the canvas was also much more frequent on tablets than on computers. Consequently, the pragmatic and hedonic qualities of the tested prototypes were lower on tablets. Two design recommendations follow for tablet-based digital concept mapping tools:

- **Enable gesture-based interaction**: Despite the technological difficulties, evidence strongly suggests that a tablet-based concept mapping tool requires support for gestures, probably by distinguishing between the number of fingers on the screen and the actions they perform. The remote whiteboard Miro (Fig. 53) is an example of such a gesture-based interaction, building on Javascript and an onboarding to demonstrate the different gestures. Such gestures could also allow tablet users to select multiple objects at once (e.g., by long-tapping and dragging a selection area over elements), a functionality that is currently unavailable on tablets.
- **Create a dedicated tablet interaction design by supporting stylus input**: Another design iteration could explore building a dedicated tablet interaction design with support for stylus input proposed by numerous participants in the studies in Chapters 2, 3, 8, and 11. Evidence suggests that such a stylus-based interaction design should implement shape and writing recognition to avoid the unintended consequences identified in Chapter 8. The technical challenges should not be underestimated, but recent developments on iPadOS like the Scribble feature[24] might facilitate development. Furthermore, follow-up research should investigate whether scores on such an optimized tablet concept mapping tool are comparable to computer-based concept map scores. Given the high emotional value that several participants attributed to handwriting, implementing such functionalities might also contribute to enhancing the hedonic quality of the concept mapping tool. The basic hand-drawing functionality looks promising as feedback was generally positive.

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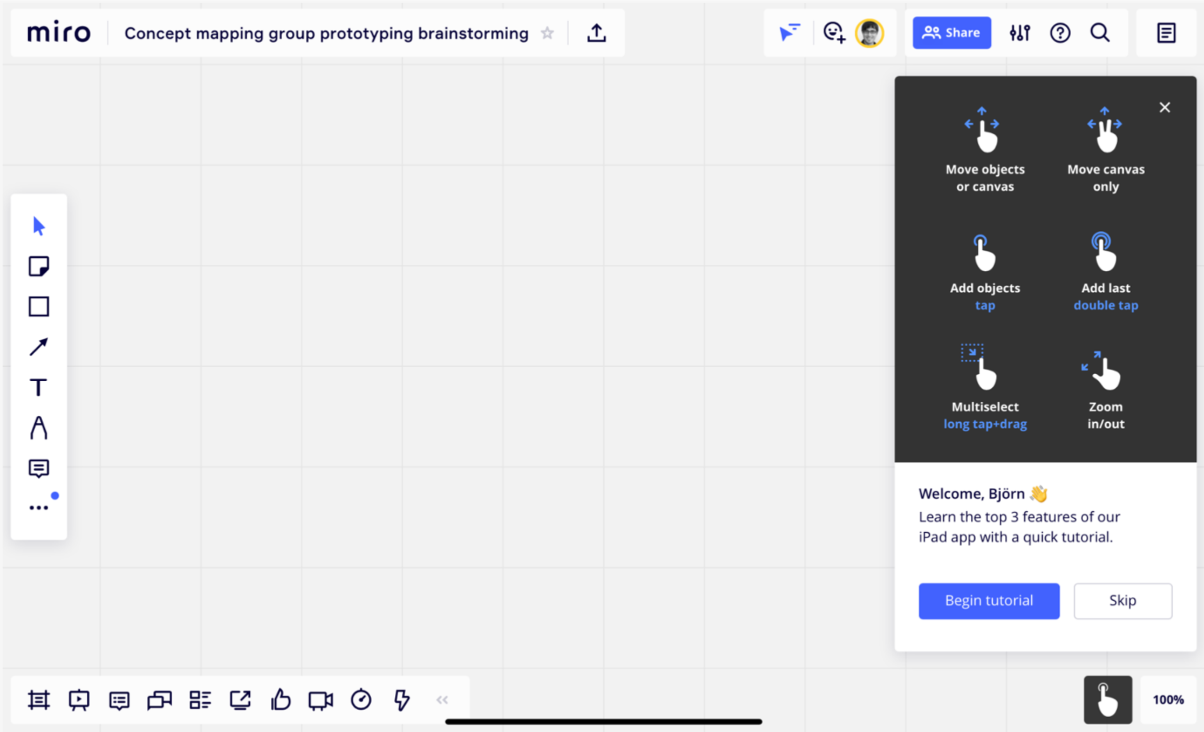
[24] Scribble allows handwriting input with text recognition in every text input field. At the time of writing of this dissertation, it is available in multiple languages, including English, German, and French. More information is available in the video: https://developer.apple.com/videos/play/wwdc2020/10106/

***Fig. 53**: Touchscreen-based interactions on Miro (https://miro.com/)*



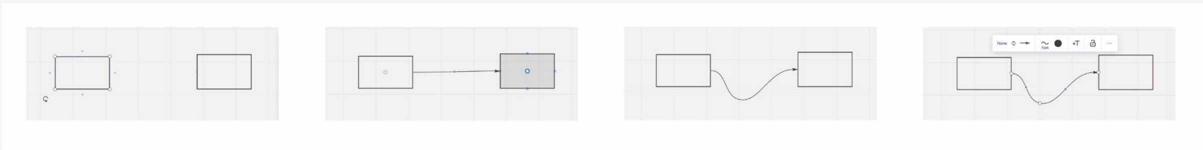
If available resources do not allow for implementing these suggestions, I recommend clearly distinguishing the dedicated modes for scrolling and zooming from other functionalities, such as positioning them as an overlay in the corner of the canvas (similar to Google Maps). Furthermore, evidence suggests that users need explicit reminders to switch scroll mode off.

9.2.3 Empower Users to Control the Link Flow

The auto-alignment of links was a serious source of frustration because it prevented users from achieving their desired results. The resulting frustration is in line with earlier findings suggesting that auto-layout can interrupt the cognitive flow of users (Mentis & Gay, 2003). Such interruptions are particularly troublesome for a concept mapping tool supposed to support users in expressing their cognitive flow. Furthermore, auto-alignment of links likely intervenes with the psychological needs of autonomy (being the cause of action instead of relying on an algorithm), control (being able to adapt the flow of lines), and self-actualizing (being able to achieve the intended result). However, the easy repositioning of elements without losing the connections is an important advantage of digital concept maps (Bruillard & Baron, 2000) that users valued.

Consequently, users need to visually adapt the flow of link lines without losing this association of connected elements. A potential solution is a Bezier-like handle in the center of each link that users can drag to new positions (see Fig. 54 for an example). It will likely create feelings of autonomy and control, thus contributing to the fulfillment of these needs.

Fig. 54: Adaption of lines in Miro (https://miro.com/)



9.2.4 Eliminate Mode Switching and Minimize Toolbar Use

An interesting finding concerned the various modes (for selecting, creating concepts, and creating links) and the toolbar. These modes were specifically designed to "represent every activity needed with a certain icon" (Weinerth et al., 2014b, p. 5). This design decision was based on a task analysis (Weinerth et al., 2014b) and evaluated in several studies (Weinerth, 2015). However, participants in the design studies described in Part III often had difficulties with the modes. In particular, they frequently clicked on elements for selecting (regardless of whether the selection mode was active) and expressed frustration due to the frequent need to switch modes for typical tasks in concept mapping.

Why would a design solution based on task analysis and proven useful in previous studies still cause pragmatic difficulties during the studies of the present dissertation? Besides the fact that several years have passed (and thus, expectations might have changed), I hypothesize that different mental models of creating concept maps exist, along with consequences in terms of the sequence of tasks. The present solution seems very organized and straightforward to represent a procedure or topic that users envision in their heads. Users could readily switch between modes optimized to create single or multiple concepts (depending on what best fits their purposes) and drag links or adapt design options afterward as appropriate.

However, users frequently showed a pattern that is closer to thinking about what they want to represent. In these cases, concept mapping was closer to being a cognitive tool (Jonassen et al., 1997) instead of a representational tool, and the creation processes were more unorganized. In such an unorganized task, the necessity to switch modes might become inefficient. This interpretation is in line with the influence of contextual factors described above: For concept mapping tasks with higher complexity, evaluations of pragmatic quality went down (although the overall interaction design approach of switching modes remained unchanged), indicating that the mode switching was experienced as more cumbersome.

A design recommendation for a follow-up iteration would be to reduce the mode-switching:

- explore an inline menu that opens on top of a selected object instead of a dedicated sidebar, resolving the need to open and close the sidebar;
- allow inline editing of labels, directly on the object, instead of using a text field in another place;
- select an element on clicking or tapping it, regardless of which tool is selected;

- consider alternatives for creating links without a dedicated mode, for example, similar to Cmap Tools (https://cmap.ihmc.us/) or Miro (https://miro.com/) that allow users to drag links out of concepts;
- reconsider the tool behavior when users drag a link to an empty area[25].

9.2.5 Optimize for Hedonic User Experience

Several design recommendations address ways to enhance the hedonic dimension of user experience. Optimizing for the fulfillment of pleasure and stimulation seems worthwhile. Evidence from the studies in Chapters 4, 8, and 11 suggests that these needs are directly connected to hedonic user experience. Thus, optimizing for these needs is promising for enhancing the hedonic user experience:

First, colorful, engaging visual aesthetics could allow the concept mapping tool to go beyond the purely functional, for example, by working with playful animations, illustrations, friendly icons, or trendy-looking gradients[26]. Such design could enhance the joy of use and contribute to the fulfillment of pleasure and stimulation.

Second, stimulation could be further enhanced with messages and prompts that motivate learners to explore concept maps. Motivational messages could enhance existing dialogues, for example, “Your concept map was saved. Open and enhance it next time to show what you have learned!”. Prompts could go further and align the needs for pleasure and stimulation with other needs. For example, a prompt could identify unlabeled links and stimulate learners to think about which label would be adequate, thus contributing to competence. Alternatively, an empty canvas (before concept map creation started) could show inspiring visuals and engaging messages instead of a blank screen[27].

9.2.6 Recommendations and Materials for Instructors

Finally, although these are not at the core of the present dissertation, my research provides clear recommendations for instructors. In Chapter 1, I outlined two fundamental approaches to addressing subjective differences between learners regarding their use of digital tools. The first approach is the

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[25] Currently, the link creation is failing without further notice, often causing frustration. Alternatives would be providing an error message (“link creation is only possible by dragging on another concept”) or creating a new concept when missing. Furthermore, there might even be cases where a link to or from an empty space makes sense, for example to denote events that are assumed to have no agent as a direct cause (Kress & Leeuwen, 2021).

[26] It should be noted that these are ideas from a brainstorming and from current design trends. For example, Pablo Stanley has popularized a particular style of illustrations of humans (https://www.humaaans.com/) that is currently being implemented in the context of functional apps like the Corona Warn App (Germany). In any case, the aesthetics should be validated to safeguard that it is timeless and functional enough to support concept mapping without looking sterile.

[27] Applied articles on UX design frequently discuss these overlooked design opportunities. See Shane Ketterman’s blog post “Empty States – The Most Overlooked Aspect of UX” (https://www.toptal.com/designers/ux/empty-state-ux-design) as an example.

notion of individual competencies like information and communication technology (ICT) literacy (Katz & Macklin, 2013; Siddiq et al., 2017), assuming that differences in competencies account for differences in digital tool use and suggesting adequate training as a requirement (Gouli et al., 2003; Jonassen et al., 1997; Weinerth et al., 2014a). The second approach is design and human-computer interaction, assuming that differences in the design of digital tools account for differences in digital tool use and suggesting adequate usability and user experience testing. These approaches are not mutually exclusive. However, throughout the studies in Chapters 7, 8, and 11, I took care not to interfere with the interaction process by not answering questions like "how do I create a link?"[28]. This behavior was necessary to inform the design of the digital concept mapping tool, but in a realistic educational setting, optimizing design and training participants would go hand in hand. Training of learners and instructors in concept mapping could address the desired outcomes and pain points that I have identified (see Chapter 3), supporting the active integration of concept mapping in educational activities. The present dissertation contributes instructional materials like brochures and video tutorials that have been prepared in close collaboration with SCRIPT and LUCET to support instructors in these activities.

[28] If these questions appeared, I took note and addressed them in debriefing.

PART IV:

Concept mapping-based Assessment

10 Scoring Concept Maps: From a Systematic Literature Review to a Comprehensive Framework

Abstract

Concept maps are a well-established approach for assessing knowledge. However, it is difficult to make an informed decision about how to score concept maps because many different criteria are used. This systematic literature review investigates criteria used to score concept maps in order to assess knowledge. We coded 550 studies and identified three dimensions along which such criteria can be synthesized: instructor uses (e.g., provide a score for each instance of a measurement), kind (different types of criteria consisting of level and mode, e.g., scoring concept map structure), and frame of reference (e.g., comparing learner and expert concept maps). We integrate these dimensions into a comprehensive framework of criteria for scoring concept maps, present research on each of the identified criteria in context, and discuss implications and research gaps. In particular, the visual features and the process of creating concept maps were found to be underexplored in research. The comprehensive framework of criteria for scoring concept maps defines and integrates various dimensions. It helps researchers and instructors in reflecting and deciding on their scoring approaches.

10.1 Introduction

Concept maps are a well-established approach in learning and assessment for complex structural knowledge (Novak & Gowin, 1984). A concept map represents a topic with concepts and directed or non-directed labeled links. A concept is a “perceived regularity in events or objects, or records of events or objects, designated by a label” (Novak, 1990, p. 29). Two concepts linked by a labeled line are known as a proposition (Ruiz-Primo, 2004). There is a wealth of studies on the educational benefits of concept maps (for a meta-analysis, see Nesbit & Adesope, 2006; Schroeder et al., 2018), for example regarding their potential to promote computational thinking (Buitrago Flórez et al., 2017). Most research on concept mapping in learning contexts has focused on the effects of concept maps on comprehension and learning, the use of concept maps as an assessment method, or a combination of both. While previous literature syntheses on concept mapping focused on their effects on learning (Nesbit & Adesope, 2006; Schroeder et al., 2018), this systematic literature review aims to provide a comprehensive overview of the criteria used to score concept maps. The variability in how concept maps are scored is large, complicating understanding and interpretation of different criteria for concept map quality. This review systematically examines scoring criteria and combines them into a framework to guide instructors and researchers in selecting appropriate criteria for their projects and teaching practices. Digital concept mapping tools increasingly provide new possibilities, such as real-time feedback or automated scoring (Weinerth et al., 2014a), that demand a thorough knowledge of criteria for scoring concept maps.

10.1.1 Background in Theories of Cognition and Memory

In the following section, we will first outline concept mapping's place in theories of cognition and memory, and second, discuss their nature as re-representations of knowledge (highlighting different variations of concept maps). Given that concept maps are used in different domains with diverging theoretical traditions, we will concentrate on the major theories of cognition and memory that have driven reflection on concept maps. Concept maps were proposed by Novak and Gowin (1984), who based them on the theory of meaningful learning (Ausubel, 1968). The theory of meaningful learning is part of a larger family of theories of cognition and memory known as semantic networking theory (Jonassen et al., 1997) or schema theories (Anderson & Pearson, 1984). Schemata are theoretical, abstract structures of knowledge (Anderson & Pearson, 1984; Seel, 2003) that are assumed to be interconnected (Jonassen et al., 1997; Rumelhart & Norman, 1978). Schemata also serve as the foundation for mental models (Rumelhart et al., 1986; Seel, 2003), which are defined as "internal representations of reality" (Shute & Zapata-Rivera, 2008, p. 5) that help to describe, explain, or predict reality (Palmunen et al., 2013). Thus, schemata and mental models are related, but serve different cognitive functions (Ifenthaler, 2006). If newly acquired information is aligned with existing schemata, humans can integrate it into their existing knowledge structure. These processes correspond to Piaget's assimilation principle (Ifenthaler, 2006; Seel, 2003). However, if new information is not aligned with existing schemata, humans need to create a mental model of the situation and adapt their knowledge structure. These processes correspond to Piaget's accommodation principle and are considered the foundation of learning (Ifenthaler, 2006; Seel, 2003). In this theoretical tradition, learning refers to the active reorganization of knowledge structures (Jonassen et al., 1997). Thus, learning results in a more advanced and interconnected structure (Lopez et al., 2014).

The theory of meaningful learning or "assimilation theory" was introduced by Ausubel (1968) and provides the theoretical foundation of concept mapping (Novak & Gowin, 1984). Like other schema theories (Anderson & Pearson, 1984), it emphasizes that learners actively connect new knowledge to existing knowledge structures. Learners refine their mental representation of concepts by making them more specific, adding new ones, or restructuring them (a process referred to as "progressive differentiation"). Furthermore, learners might start to see connections between concepts in formerly disjunct areas (a process referred to as "integrative reconciliation", typically visualized with crosslinks between different sections of a concept map; Novak, 2010).

10.1.2 Concept Maps as Actively Constructed Re-representations

A challenging aspect of knowledge assessment is that it is not possible to directly observe cognitive structures (Ifenthaler, 2010b). Instead, learners have to communicate them with appropriate methods (Ifenthaler, 2010b). Concept maps and related forms of knowledge visualizations are assumed to be one of these appropriate methods because they are assumed to represent mental structures of knowledge (Jonassen et al., 1997), particularly semantic long-term memory (Jacobs-Lawson & Hershey, 2002). However, it is important to emphasize that concept maps are not direct mirrors of cognitive structures. Concept mapping is the process of creating concept maps (Jonassen et al., 1997) and has been described as an internal negotiation: While learners create their concept maps, they have to constantly consider how they are expressing their knowledge in a constructivist fashion (Jonassen & Marra, 1994; von Glasersfeld, 1989; Shymansky et al., 1993; Novak, 1990). Thus, concept mapping is an active construction process in which learners re-represent their mental models and schemata (Ifenthaler, 2010b). Therefore, concept mapping is itself a learning process (Jacobs-Lawson & Hershey, 2002) because learners become more and more aware of their cognitive structures (metacognition). This process is mediated by various factors, such as the concept mapping task (Ruiz-Primo & Shavelson, 1996), individual skills (Erdogan, 2009; Ifenthaler, 2010b) or the design of the tool used to create concept maps (Weinerth, 2015).

Different variations of concept maps allow learners to re-represent particular aspects of knowledge. We will discuss these variations of concept maps with regards to three dimensions: their general structure, the role of dynamic aspects, and the distinction between concept maps and related visualizations.

First, variations of concept maps differ regarding their general structure. Novak and Gowin (1984) originally proposed that concept maps should be organized hierarchically, which was linked to the assumption that memory is also hierarchically structured (Ruiz-Primo & Shavelson, 1996). Concept maps in this tradition are created with the most inclusive concept at the top. Propositions close to the top capture general knowledge, while more specific propositions are farther down (Jacobs-Lawson & Hershey, 2002). However, other theories of cognition and memory stress that meaning stems from the relations between concepts (Deese, 1965). Thus, concept maps in this tradition have a non-hierarchical network structure (Ruiz-Primo & Shavelson, 1996; Lopez et al., 2014).

Second, variations of concept maps differ regarding the emphasis they put on dynamic aspects, such as feedback loops, which are hard to capture in hierarchical concept maps (Palmunen et al., 2013; Safayeni et al., 2005). These variations of concept maps use positive and negative arrows to demonstrate how changes in one concept affect associated concepts (Safayeni et al., 2005). In addition, there are a large variety of visualizations illustrating specific kinds of processes, such as flowcharts.

Third, despite their success in education, concept maps are not the only graphical representation of knowledge, particularly with respect to labelling relations. Closely related to concept maps are cognitive maps, knowledge maps, and mind maps. Cognitive maps do not explicitly specify the relationships between links. Thus, they visualize which associations between concepts exist for participants, but not the exact semantic relations between these concepts (Shavelson et al., 2005). Knowledge maps specify the semantic relationships between links but only permit the use of a fixed set of link labels (Schroeder et al., 2018). Mind maps are networks of associations connected to a central topic with branches of related topics. They build on a wide range of graphical features (Buzan & Buzan, 2010; Davies, 2011) and are used for a diverse set of activities, including brainstorming or note-taking (Buzan & Buzan, 2010). These visualizations are typically created to generate ideas or communicate simple relations between ideas rather than explicit semantic relations (Kinchin et al., 2005; Shavelson et al., 2005). Finally, there are different methodological traditions referred to as "concept maps". The method of "collaborative concept mapping" (Kane & Trochim, 2008) or "group concept mapping" (Goldman & Kane, 2014) shares the name "concept map", but captures a different approach. In a first step, participants generate and sort idea statements about a topic of interest. In a second step, a multivariate statistical algorithm transforms these statement groups into aggregated clusters for further analysis.

Concept mapping can serve a broad range of functions. In this paper, we focus on using concept maps for assessment and present a systematic framework of criteria used to score concept maps. The objective of this framework is first to identify research gaps, and second to guide researchers and instructors in selecting appropriate criteria for scoring concept maps.

10.1.3 Assessment with Concept Maps: A Large Variety of Tasks

Concept maps have been used for assessment purposes since their earliest beginnings (Novak & Gowin, 1984). Assessment refers to "the planned process of gathering and synthesizing information relevant to the purpose of (a) discovering and documenting students' strengths and weaknesses, (b) planning and enhancing instruction, or (c) evaluating progress of making decisions about students" (Cizek, 1996, p. 10). Thus, assessment refers to any attempt to evaluate a learner's work (Sadler, 1989), including (but not limited to) assigning grades. Concept maps are useful both for summative and formative assessment. The objective of summative assessment is to evaluate students' achievement after a series of teaching units in order to assign a grade (Sadler, 1989). The objective of formative assessment is to diagnose learning with the aim of adapting instruction (Black & Wiliam, 1998) and providing feedback to students (Sadler, 1989).

As outlined in the previous sections, concept maps hold the potential to assess cognitive structures. However, as visualizations of these structures actively created by learners, concept maps are necessarily biased to a certain extent, and researchers and instructors should carefully consider their approaches to designing and scoring concept maps. When concept maps are used for assessment, a prominent approach is to distinguish between the response format, task, and scoring (Ruiz-Primo & Shavelson, 1996). The response format includes aspects of administration mode (e.g., computer-based, oral, or paper-based concept mapping), characteristics of the response (e.g., a hierarchical map to be filled in vs. a blank slate), and who creates the map (e.g., the students themselves working individually, teachers based on students' answers to a series of questions, or students in a collaborative setting; Basque & Lavoie, 2006; Stoyanova & Kommers, 2002). Concept mapping tasks can vary with regard to several aspects. First, there are differences in what learners are supposed to do, e.g., create a concept map from scratch or enrich a provided map (Cañas et al., 2012). Second, there are differences in how much freedom learners have, e.g., whether they are allowed to use their own terms or have to select terms from a given list. Finally, there are differences in content constraints to be followed, e.g., whether the concept map has to be hierarchical. Thus, concept mapping tasks have been positioned on a continuum of directedness (Ruiz-Primo, 2004). On one end of the continuum, tasks with high directedness provide learners with concepts they should use, leaving them comparatively little freedom (Strautmane, 2012). However, this task type still allows for many variants: In some cases, only provided concepts can be used, while in other cases, students may enrich the provided concepts with their own (Strautmane, 2012). Additionally, researchers have created concept mapping tasks where students had to find errors in a concept map (Corrêa et al., 2018). On the other end of the continuum, low-directed tasks ask students to create their maps freely, with no restrictions. These tasks allow students to represent their knowledge more precisely, but also require more content knowledge (Strautmane, 2012). In general, high-directed tasks are considered easier for learners (Anohina-Naumeca et al., 2011). Cañas, Novak and Reiska expanded the directedness continuum into a two-dimensional model with freedom of structure on the x-axis and freedom of content on the y-axis (Cañas et al., 2012). Finally, another variant is whether or not distractors are present (Strautmane, 2012).

Himangshu and Cassata-Widera (2010) provided a systematic literature review of studies on the concurrent validity of concept mapping in the science domain with other achievement measures. They summarized the different dimensions of concept mapping tasks into three typical concept mapping approaches. Their results indicate that studies using concept mapping tasks with a high level of directedness ("fill-in-the-blank" activities) typically report higher correlations with traditional assessment methods than studies of concept mapping tasks with a low level of directedness.

In summary, many different concept mapping tasks are available for summative and formative assessment, making the selection of adequate scoring criteria difficult. Concept maps are increasingly created with digital tools, which provide certain advantages over paper-and-pencil concept maps, for example by automatizing the assessment procedure (Strautmane, 2012). Thus, the variability of digital formats and devices for concept mapping introduces additional complexity when choosing relevant scoring criteria. However, assessment is a high-stakes operation whose quality relies on the choice of an appropriate scoring approach.

10.1.4 Scoring concept maps and position of the present review

Scoring concept maps involves conducting a systematic evaluation of students' responses, which is then used to infer information about learners' knowledge (Ruiz-Primo, 2004). Thus, researchers and instructors need solid knowledge of the criteria that can be observed through concept maps and how these criteria can be used to infer information about learners (i.e. knowledge, mental representation, learning process). Numerous papers have presented overviews of concept map scoring. Ruiz-Primo and Shavelson (1996) and Constantinou (2002) distinguished between evaluating various components of a map's content (that is, different elements that make up a concept map, e.g., the quality of the propositions), comparing a student map to a reference map, and combinations of both. Anohina and Grundspenkis (2009) classified concept map scoring into five dimensions: type of scoring (quantitative, qualitative, both), scoring method (structural, relational, both), use of an expert map (yes or no), automatic or manual scoring, and whether restrictions exist (e.g., only applicable to hierarchical concept maps). Their paper mentions 16 different scoring schemes based on various combinations of these dimensions. Strautmane (2012) distinguished between scoring content by evaluating components, scoring structure, and a collection of various other methods. She found 21 scoring methods based on components, 16 based on structure, and 5 in the "other" category. Venkatesan et al. (2017) included seven evaluation models, one scoring algorithm, and scoring via comparison to an expert map in their review. Dixon (2014) distinguished between quantitative and qualitative scoring. In particular, he demonstrated the usefulness of a qualitative approach to assessing concept maps, for example to discover relevant themes within a topic. Wheeldon (2010) built on the distinction between quantitative and qualitative methods and suggested that concept maps are particularly appropriate for quantitative scoring, while mind maps are more appropriate for qualitative scoring due to their higher flexibility. Keppens and Hay (2008) discussed four quantitative methods (holistic scoring, structural scoring, relational scoring, closeness index) and three qualitative methods (linkage analysis, types of map structure, and qualitative simulation where students use a causal concept map to program an autonomous agent to respond to quiz questions). Petrović et al. (2013) reviewed quantitative and qualitative criteria for scoring concept maps together with a range of methods for comparing the similarity of concept maps. Krabbe (2014) drew upon Ruiz-Primo and Shavelson (1996)'s distinction, but expanded it to include visual analysis and creating an average map from a group of learners' individual concept maps. Furthermore, he introduced different criteria developed in the German-speaking research community to make these accessible for an international audience. Finally, Watson et al. (2018) distinguished between calculating scores based on an expert map, three quantitative (counting components, composite metrics, proximity or similarity between maps) and four qualitative (holistic rating, proposition rating, analytic rubric, coding concepts and links) approaches.

The original contributions made by the present systematic literature review are to identify and systematize the dimensions that distinguish scoring of concept maps, provide a comprehensive overview of the criteria used to score concept maps, and present information about the contexts in which concept maps are used for assessment. Thus, the present systematic literature review extends prior overviews in several respects: in its use of a systematic strategy to identify studies, its focus on assessment criteria, and its systematization of the dimensions of scoring concept maps. First, regarding the use of a systematic strategy to identify studies, all but one of the mentioned overviews do not explicitly discuss the search strategies and selection criteria applied to identify the studies that formed the basis of their reviews. Thus, it is hard for other researchers to verify whether all relevant works related to concept map assessment have been acknowledged. The notable exception is Watson et al. (2018) who based their overview on a search using the keyword "concept map + scoring" in three databases. However, researchers and instructors might use a range of alternative terms to describe how they made sense of concept maps, such as "analyzing" or "assessing" concept maps. Thus, we consider it important to include a range of alternative terms in order to ensure that all relevant publications have been identified and to use a "referential backtracking" strategy to find additional sources (Alexander, 2020). As our brief account points out, prior overviews of concept map scoring overlap, but do not fully align because each paper identified approaches undiscovered by the others. Thus, a systematic literature review is promising, as it is likely to uncover criteria that prior work has not reported. Second, regarding the focus on criteria, prior overviews sought to identify scoring methods, not individual scoring criteria. For example, comparing a concept map created by a learner to an expert map could be carried out by matching propositions, creating a similarity criterion like the closeness index, or counting components. Thus, a systematic framework of criteria used for concept map scoring is still lacking and could substantially help researchers and instructors make informed choices about which specific criteria are best suited for their particular interests. Third, existing overviews report their results along very different dimensions, for example quantitative versus qualitative scoring or structure versus content scoring. How exactly these different dimensions relate to each other remains unclear, for example whether structural scoring is conducted more often quantitatively.

10.1.5 Research questions

Given the described complexity and variety of concept map scoring, the present paper conducts a systematic literature review to provide a comprehensive framework of criteria for scoring concept maps. Such a framework can serve as a guide to researchers and instructors in selecting and interpreting the many different criteria that have been proposed. The framework is also intended to identify research gaps and challenges regarding the criteria used to score concept maps. Thus, the study's research questions (RQs) are defined as follows: What dimensions exist to distinguish the different criteria (RQ 1)? Which criteria are used in scoring concept maps to assess knowledge (RQ 2)? In which contexts are different criteria used (RQ 3)?

RQ 1 identifies the relevant dimensions that distinguish criteria for scoring concept maps and thus provides a foundation for the comprehensive framework. RQ 2 identifies and presents the individual criteria within this comprehensive framework. RQ 3 identifies contextual factors to clarify the settings in which concept maps are scored. In particular, we examine the domains, levels of education, details about the concept mapping task, and cognitive processes evaluated with concept maps.

10.2 Method

We conducted a systematic literature review following the PRISMA-P approach to systematic literature reviews (Moher et al., 2015) as outlined in this section.

10.2.1 Criteria for inclusion and exclusion

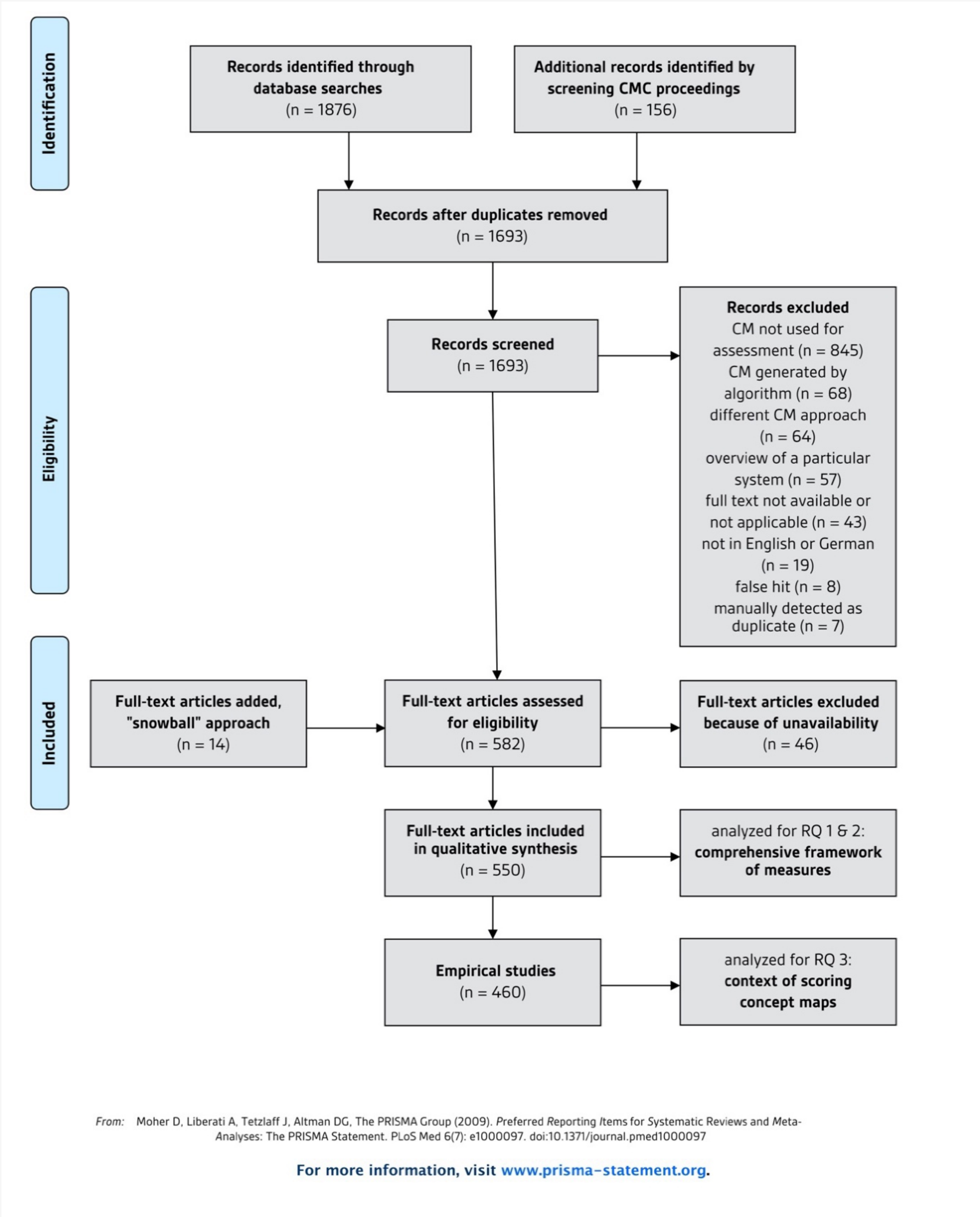
We decided to search for full papers and dissertations in English and German. We included dissertations because they present relevant work on concept map scoring. We did not limit the publication date. We excluded papers where only the abstracts were in English or German, but the full papers were in another language. For example, Cicuto and Correia (2013) provide an English abstract, but the full paper is in Portuguese. Likewise, we excluded papers that did not score concept maps for assessment purposes. For example, Amadieu et al. (2009) used concept maps with different structures (hierarchy and network) as a navigation system in learning with hypertext material, but measured knowledge with a multiple-choice test. Furthermore, we were interested in papers that used concept maps in the sense of node-link diagrams, not papers that used the cluster-based approach of “collaborative concept mapping” (Kane & Trochim, 2008) or “group concept mapping” (Goldman & Kane, 2014), as specified in the introduction section.

10.2.2 Retrieval of relevant studies

We used the following databases as sources: Education Resources Information Center (ERIC), SCOPUS, the American Psychological Association's PsycINFO database, and PSYNDEX, the database of German-speaking psychological research maintained by the ZPID (Leibniz Institute for Psychology). We selected these databases because of their wide scope in terms of different areas of research. Furthermore, we checked for additional sources of relevant papers on concept map scoring to extend our search results (Alexander, 2020). Thus, we included the proceedings of the Concept Mapping Conference (CMC), which specifically focuses on concept mapping. Regarding the search terms, we decided to examine the term “concept map” and not similar methods to make sure that we were explicitly targeting papers that position themselves within the concept mapping approach. However, we wanted to employ a range of alternative terms in both English and German referring to assessment (Alexander, 2020). Thus, we decided on the following search terms in titles, abstracts, and keywords: “concept map” AND evaluation, “concept map” AND scoring, “concept map” AND score, “concept map” AND auswertung, “concept map” AND test, “concept map” AND review, and “concept map” AND assessment.

After the search, 1,693 resources remained after removing duplicates (cf. Fig. 55). Titles, keywords, and abstracts were scanned to decide whether to include or exclude each paper. In cases where the information in the title, keywords, and abstract was not sufficient, we retrieved the full paper and read the methods section. 582 papers met our inclusion criteria. Two university libraries and international loans were used to get access to these papers. However, 46 papers remained inaccessible.

Fig. 55: *Flow chart of the present systematic literature review*



Furthermore, we applied a "referential backtracking" approach (Alexander, 2020) to include additional resources: In cases where the authors referred to a scoring method described in another paper, we verified whether this source paper was already in the corpus. If not, we added it, resulting in 14 additional papers. If the paper was found to be a literature review of concept map assessment, it was highlighted and included in the introduction and results section of the present article. In the end, 550 papers were eligible for further analysis. The full list of included articles is available in supplementary table S1 (https://rohl.es/dissertation).

10.2.3 Coding procedure

In order to create a framework of criteria for scoring concept maps (RQs 1 and 2), we followed a four-step coding process. First, the first author reviewed the existing overviews of concept map scoring discussed above. This resulted in a first draft of the framework. We applied this framework during a first round of coding of a subset of papers and identified the following commonly shared dimensions: distinguishing between quantitative and qualitative scoring, scoring of components, comparing a learner's concept map to an expert's concept map, and distinguishing between scoring content and scoring structure. Second, we discussed the framework draft as a group and refined it to make the relations between the different dimensions more explicit. We applied this second framework draft to the entire set of papers. Third, we discussed the second draft framework once again, refined and re-applied it to the entire set of papers. During this third round of coding papers, we found that no further adaptations of the framework were necessary. Fourth, we performed an independent check of our framework. As our framework involves a substantial number of interpretative qualitative analyses across different dimensions, we decided to check reliability using a consensus approach (Blandford et al., 2016; Syed & Nelson, 2015). Thus, we introduced our framework to two independent coders. Each coder practiced the framework by coding 21 randomly selected papers, which were discussed with the first author. After the two independent coders had indicated that their questions about the framework were answered, they independently coded 46 (coder 1) and 41 (coder 2) randomly selected papers (15.8% of the included papers). We discussed remaining disagreements and reached a consensus that we incorporated into a fourth iteration of the framework. We make detailed definitions of each dimension in the framework and the full list of included papers available as supplementary table S2 (https://rohl.es/dissertation). This move towards open science will allow the research community to build upon our work and help our framework evolve as work on concept map scoring continues.

Regarding the criteria used to score concept maps (RQ 2), we identified and systematized the reported criteria in accordance with the dimensions of the comprehensive framework. We extracted key information about the different criteria applied to score concept maps in the results section. Furthermore, we compiled guidelines for instructors and researchers as a supplementary file S3 (https://rohl.es/dissertation) which contains details about the application of the different criteria.

Regarding the contexts of scoring concept maps (RQ 3), we excluded papers from our corpus based on additional criteria. As this research question addresses empirical aspects of scoring concept maps, we excluded all papers that were not based on empirical data. 460 empirical papers remained eligible for investigating the domains, levels of education, details about the concept mapping task, and cognitive processes evaluated with concept maps.

- To classify the domains, we used the Fields of Science and Technology (FOS) by the OECD (OECD, 2007), which distinguishes between natural sciences, engineering & technology, medical & health sciences, agricultural sciences, social sciences, and humanities. In addition, we added a "general knowledge" category for general topics like "moving to a new location" (DeFranco et al., 2012). To classify the study participants' levels of education, we used the International Standard Classification of Education (ISCED) by UNESCO (UNESCO Institute of Statistics, 2012), which distinguishes between eight levels, from early childhood education to doctoral education or equivalent. In addition, we added a code for the professional level (e.g., employees) and retired participants.

- To classify the concept mapping tasks, we applied the taxonomy proposed by Cañas et al. (2012), with a few additions where necessary. Specifically, we coded predefined concepts, predefined link labels, "fill-in-the-blank" activities, focus questions, distractors, individual and collaborative concept mapping, predefined concept map content to be enriched (e.g., root concept or skeleton concept map), and concept mapping tasks involving critiquing or elaborating predefined concept maps. Fig. 58 includes definitions of all dimensions for concept mapping tasks.
- When classifying the cognitive processes, it should be noted concept mapping can serve different purposes. First, concept maps can reflect recall of information, either before or independently of any instruction (prior knowledge) or after instruction. Second, concept maps can reflect comprehension processes when they are completed during learning, e.g., as a note-taking method. Third, concept maps can reflect reasoning they are completed as learners work on solving a problem. Such problem-solving relies not only on structural knowledge, but also on being able to identify causes and components that influence a problem (McKeown, 2009). Finally, concept maps can serve communicative purposes when they are constructed to illustrate and discuss ideas. We also coded combinations of these types.

10.3 Results

Based on our systematic literature review, we found three dimensions for our framework of criteria for scoring concept maps (see Fig. 56). Here, we introduce these dimensions (RQ 1).

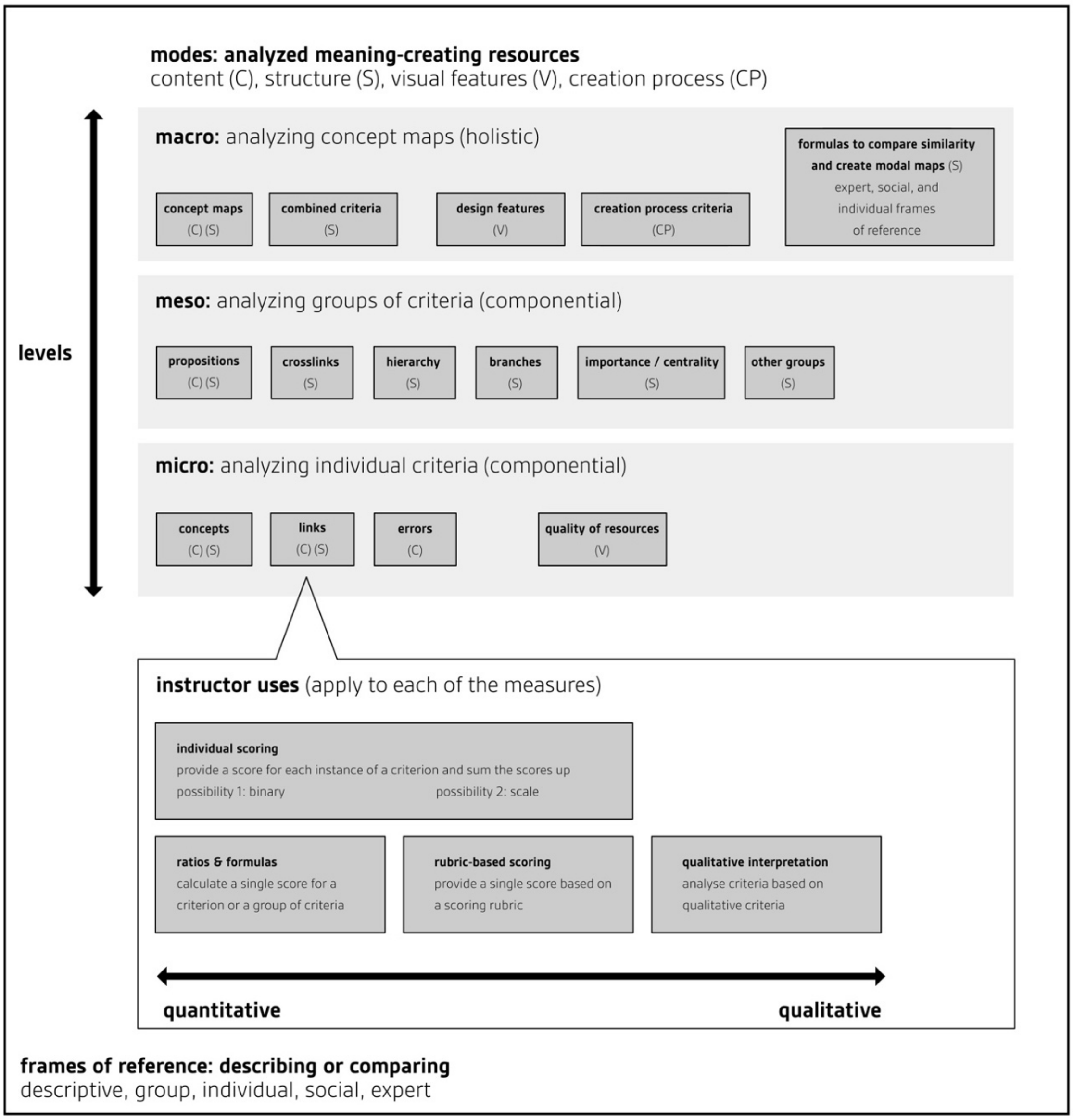
1. The first dimension refers to *instructor uses* of criteria to generate scores, that is, the actions instructors perform in order to score concept maps. For example, instructors might give points each time a criterion is present and then sum up these points. We use the term "instructor use" throughout the present paper because concept mapping is predominantly done in educational settings or educational research, but researchers could use the same methods to score concept maps in other contexts. Instructor uses can be applied to different criteria.
2. The second dimension refers to the *kind* of criterion, which consists of the *level* of analysis (e.g., scoring componential criteria like the presence or absence of certain concepts, or scoring holistic criteria referring to the entire concept map) and the *mode* (that is, the resource that creates meaning [Bezemer & Kress, 2008], e.g., content or structure). Different kinds of criteria relate to different ways of expressing and analyzing information in a concept map. They also

reflect different cognitive processes and help to "read" the visualization of knowledge structures contained in a concept map.

3. The third dimension refers to *frames of reference*, that is, whether the criteria are used to compare or describe concept maps (Fischbach et al., 2015). The frame of reference relates to the goal of scoring (e.g., to compare different learners to one another or match learners' answers with an ideal solution) and influences the specific criteria selected.

In the following sections, we describe the identified dimensions in detail and synthesize the criteria uncovered in the systematic literature review according to these dimensions (RQ 2). Furthermore, we provide essential information for their use. Additional materials, including detailed scoring instructions, are available as supplementary file S3 (https://rohl.es/dissertation). Figure 56 provides an overview of the framework.

Fig. 56: *Framework of criteria for scoring concept maps*



10.3.1 Instructor uses for scoring concept maps

Our systematic literature review found four distinct instructor uses of scoring criteria. The first instructor use is to individually score the extent to which a criterion appears (e.g., number of propositions), either through simple counting (1 point for each correct proposition) or by scoring the criteria on a scale (e.g., 0-2 points per proposition depending on its quality). Instructors typically count the number of occurrences for each criterion when they want to clearly separate correct and incorrect answers. Scoring criteria on a scale is appropriate when instructors want to maintain differences in the quality of answers. The second instructor use is to apply a ratio or formula to generate a single score based on a criterion or group of criteria. An example is to divide the sum of valid propositions by the total number of propositions. The third instructor use is to use a scoring rubric. A rubric is an assessment method that describes performance criteria at different levels of performance (Hafner & Hafner, 2003). An example would be to assign the overall quality of all propositions taken together with 0-5 points based on predefined criteria. Rubric-based scoring is typically applied when researchers or instructors want to avoid a situation in which aggregating scores on individual criteria results in similar scores for very different concept maps (Kinchin et al., 2000). The fourth approach is qualitatively assessing or interpreting concept maps in order to answer a question of interest. An example is to interpret how well concept maps created by the same learners at different points in time reflect their progression of thought (Clary et al., 2009).

Following suggestions in prior overviews of concept map scoring (Anohina & Grundspenkis, 2009; Dixon, 2014; Keppens & Hay, 2008; Petrović et al., 2013; Venkatesan et al., 2017; Watson et al., 2018; Wheeldon, 2010), it is possible to position these instructor uses on a continuum ranging from quantitative to qualitative (cf. Figure 56). We present the individual criteria for scoring concept maps along with the typical instructor uses they are associated with in the following sections.

10.3.2 Kinds of Criteria: Levels and Modes

A wide variety of componential and holistic criteria are used to score concept maps. Our framework includes two dimensions that are useful in distinguishing between different kinds of criteria: level and mode. Criteria for scoring concept maps vary in their scope, ranging from scoring each individual concept to scoring a concept map as a whole. We defined such differences as levels, and positioned the criteria at the micro (individual criteria), meso (groups of criteria), or macro levels (entire concept map). Criteria at the micro and meso levels are componential in the sense that several different components of concept maps are considered independently, e.g., propositions and hierarchical levels. Criteria at the macro level are holistic in the sense that the concept map is considered as an integrated whole. Furthermore, criteria vary in the mode through which they make sense of concept maps. "Mode" (or "modality") has been defined as "a socially and culturally shaped resource for making meaning" (Bezemer & Kress, 2008, p. 171). We identified four different modes of criteria for scoring concept maps:

1. *Content* criteria assess what a concept map communicates explicitly; for example, the labels of the concepts included in the map.
2. *Structural* criteria assess structural features of a concept map, such as the number of concepts and links. Structural criteria often build on graph theory and are frequently used in digital concept mapping. Graph theory investigates graphs (or networks) that are made up of nodes (or vertices) connected with lines (or ties or edges). Lines can be directed or undirected (Benjamin et al., 2015). Most structural criteria used in concept map scoring consider a concept map as an undirected graph. The rationale behind this assumption is that the direction of a proposition can easily be reversed, for example by using a passive construction instead of an active or by using another linking term (Krabbe, 2014). However, we also found a small set of criteria that consider concept maps as directed graphs, thus preserving the direction of a proposition.

3. Criteria relating to *visual features* score the design of a concept map, like the colors used to represent concepts.
4. Criteria related to *creation processes* score how a map is constructed (e.g., examining log files containing the various creation steps completed by students, like adding concepts or creating links in digital concept mapping).

10.3.3 Micro-level Criteria: Concepts, Links, and Errors

The micro level criteria used to score concept maps concern the basic building blocks of concept maps (concepts and links) as well as individual errors that learners made. This level is comparable to studying vocabulary in linguistics and mostly covers content criteria (with the exception of counting concepts and links). Table 11 lists the content and structural criteria and instructor uses found in our systematic literature review on the micro level.

Table 11*: Criteria and Instructor uses for scoring concept maps*
(C = Content, S = Structure, micro level)

Criterion		individual		ratio	rubric	qualita-tive	combi-nations
		binary	scale				
Concepts	categories (C)	89 (16.2%)	34 (6.2%)	6 (1.1%)	9 (1.6%)	5 (0.9%)	11 (2.0%)
	quality (C)	24 (4.3%)	35 (6.4%)	9 (1.6%)	20 (3.6%)	2 (0.4%)	4 (0.7%)
	origin (C)	4 (0.7%)		1 (0.2%)	2 (0.4%)		
	language (C)	4 (0.7%)	2 (0.4%)				
	number (S)	69 (12.5%)	2 (0.4%)				
Links	quality (C)	2 (0.4%)	3 (0.5%)		3 (0.5%)	1 (0.2%)	1 (0.2%)
	number (S)	44 (8.0%)	3 (0.5%)	8 (1.5%)	1 (0.2%)		1 (0.2%)
Errors	category (C)	2 (0.4%)	2 (0.4%)		2 (0.4%)		
	number (C)	3 (0.5%)	2 (0.4%)	1 (0.2%)			
	identification (C)		1 (0.2%)	2 (0.4%)			

Concepts: The most relevant scoring methods for concepts are their category, quality, and origin. A frequent approach is to focus on particular categories of concepts in scoring, e.g., to award 1 point for each example (Novak & Gowin, 1984) or to score concepts related to domain-specific content categories (Segalàs et al., 2010). Quality of concepts can be taken into account, for example, by defining key concepts for the concept map's domain and then calculating ratios of essential to secondary concepts (Calafate et al., 2009). The origin of concepts is used when instructors provide learners with a list of suggested concepts that they can enrich with their own ideas. For example, relevant concepts that were not provided can be awarded additional points (Rivard & Straw, 2000). Finally, structural scoring of concepts is possible by counting the number of concepts in a concept map. This measure is known as a network's "order" in graph theory (Benjamin et al., 2015) and usually interpreted as indicative of the complexity of a concept map (Ifenthaler, 2010a).

Links: A link is a labeled or non-labeled relationship between concepts. The combination of a link and two or more concepts makes up a semantic unit called a "proposition" (Novak & Gowin, 1984). Links are typically scored structurally by counting their number, which is referred to as the "size" of a network in graph theory (Benjamin et al., 2015). Propositions are often scored based on their content (accuracy of the described relation) (Taricani & Clariana, 2006) and will be covered later, as they represent criteria on the meso level.

Errors: Errors are often taken into account when scoring other criteria by discarding non-valid answers. However, errors might also be informative for understanding learners' thought processes (Kinchin et al., 2000). Thus, it is possible to subtract points for each error that learners made (Terrio & Auld, 2002) or to count different kinds of errors (Conradty & Bogner, 2008). There are also concept mapping tasks where learners have to identify errors in a provided concept map (Correia et al., 2016).

10.3.4 Meso-level Criteria: Propositions, Crosslinks, and Clusters of Propositions

Criteria on the meso level used to score concept maps address components made up of combinations of concepts and links, comparable to a sentence in linguistics. Table 12 lists the content and structural criteria and instructor uses found in our systematic literature review on the meso level.

Table 12*: Criteria and Instructor uses for scoring concept maps (C = Content, S = Structure, meso level)*

Criterion		individual		ratio	rubric	qualita-tive	combi-nations
		binary	scale				
Propo-sitions	quality (C)	91 (16.5%)	90 (16.4%)	16 (2.9%)	26 (4.7%)	4 (0.7%)	28 (5.1%)
	importance (C)	2 (0.4%)	17 (3.1%)	1 (0.2%)			1 (0.2%)
	categories (C)	18 (3.3%)	18 (3.3%)	6 (1.1%)	1 (0.2%)	1 (0.2%)	3 (0.5%)
	number (S)	34 (6.2%)	3 (0.5%)	1 (0.2%)			1 (0.2%)
Crosslinks	number (S)	36 (6.5%)	97 (17.6%)		10 (1.8%)	1 (0.2%)	1 (0.2%)
Hierarchy	number (S)	31 (5.6%)	84 (15.2%)		13 (2.4%)		
	concepts per level (S)	9 (1.6%)	5 (0.9%)	1 (0.2%)		1 (0.2%)	1 (0.2%)
Importance / centrality (S)		21 (3.8%)	1 (0.2%)	3 (0.5%)			1 (0.2%)

Branches	number (S)	19 (3.5%)	15 (2.7%)		1 (0.2%)		
	concepts per branch (S)	1 (0.2%)		1 (0.2%)			1 (0.2%)
Other groups	quality of clusters (C)	1 (0.2%)	2 (0.4%)			1 (0.2%)	
	sub-networks (S)	15 (2.7%)		2 (0.4%)			
	loops / cycles (S)	2 (0.4%)					

Propositions: Propositions are the most prominent meso level criterion in concept map scoring. They have been described as the "basic unit of meaning in a concept map" (Ruiz-Primo & Shavelson, 1996, p. 570). Propositions are typically scored as content criteria, with the exception of the structural criterion of simply counting the number of propositions. Content criteria for propositions most frequently consider the quality, relevance, or category of a proposition. Scoring the quality of propositions is typically done by awarding credit for each valid proposition, either binary with 1 point for correct and 0 points for incorrect (Novak & Gowin, 1984), or by using a quality scale, e.g., from 0-3 points depending on the accuracy of a proposition (Yin et al., 2005). A second method is to consider how important a proposition is for the topic and adapt the amount of credit accordingly. Thus, digital concept mapping tools can include a weighting factor as a parameter to be used in calculating scores (Shui-Cheng et al., 2002). Finally, a significant amount of scholarly work is based on distinguishing between different categories of propositions: for example, to score the interdisciplinarity of a concept map (Reiska et al., 2018).

Crosslinks: Special attention is often paid to crosslinks, defined as links between different branches of a concept map (Hao et al., 2010). They are interpreted as reflecting "integrative reconciliation" (Novak & Gowin, 1984): When learners realize that concepts from different branches are related, they might use crosslinks to indicate this relationship. Therefore, crosslinks are usually scored higher than regular propositions: for example, with 10 points for each crosslink (Novak & Gowin, 1984).

Hierarchical levels: A frequently used measure is the number of hierarchical levels. Hierarchical levels are usually interpreted as indicators of progressive differentiation and integrative reconciliation in hierarchically structured concept maps. A typical instructor use is to award a specified number of points per hierarchical level (e.g., 5 points; Novak & Gowin, 1984). A smaller number of studies count the number of concepts per hierarchical level (Jacobs-Lawson & Hershey, 2002).

Importance of concepts in the proposition structure: Several criteria attempt to specify the importance of concepts by interpreting the propositional structure. Identifying the most inclusive concept is particularly relevant. It is normally interpreted as the central or most important concept that forms the starting point for progressive differentiation (Novak, 2010). Most frequently, structural criteria are applied to specify the importance of concepts. For example, Morine-Dershimer (1993) suggested specificity and centrality. *Specificity* refers to the number of concepts in a particular category divided by the total number of concepts (Morine-Dershimer, 1993). *Centrality* is defined as the number of levels a particular concept category is removed from the central concept (Morine-Dershimer, 1993).

An alternative to specifying the importance of concepts is *degree centrality*. Degree centrality investigates the importance of a concept by counting the number of direct links to other concepts. The higher a concept's degree centrality, the more important it is in the overall network (Clariana et al., 2013). Degree centrality is often calculated without considering the direction of a link, but it is possible to distinguish between ingoing and outgoing degree centrality (Shallcross, 2016). This approach makes it possible to distinguish concepts that are used to explain other concepts (high out-degree) from those explained by other concepts (high in-degree; Reiss & Haussmann, 1990). Finally, the degree centrality of individual concepts can be extended into graph centrality, which provides information about the form of a concept map (Clariana et al., 2013).

Criteria like degree centrality interpret the number of connections as a sign of importance, but there is also another way that concepts can be important: they can serve as important *bridges* between different areas of a concept map. Such bridges can be defined as concepts that, if they were removed from the concept map, would split the concept map up into different submaps (Austin & Shore, 1995; Bernd et al., 2000).

Branches: A less frequent set of criteria focuses on counting the number of branches. A branch is defined as a sub-tree in a concept map (Hao et al., 2010). Branches can also be scored by determining their depth, that is, the number of concepts in the longest branch (Bielefeldt, 2016).

Other groups of propositions: Finally, researchers have explored a range of alternative ways to identify and score groups of propositions, mostly via structural criteria like counting sub-networks (Eckert, 1998), loops of three or more concepts (Luckie et al., 2011), or applying clustering algorithms (McGowen & Davis, 2019; Siew, 2018).

10.3.5 Macro-level Criteria: Concept Maps and Combinations

Criteria on the macro level used in scoring concept maps represent holistic criteria that take the entire map as their object of investigation. This level is comparable to studying a text in linguistics. Table 13 lists the content and structural criteria and instructor uses found in our systematic literature review on the macro level.

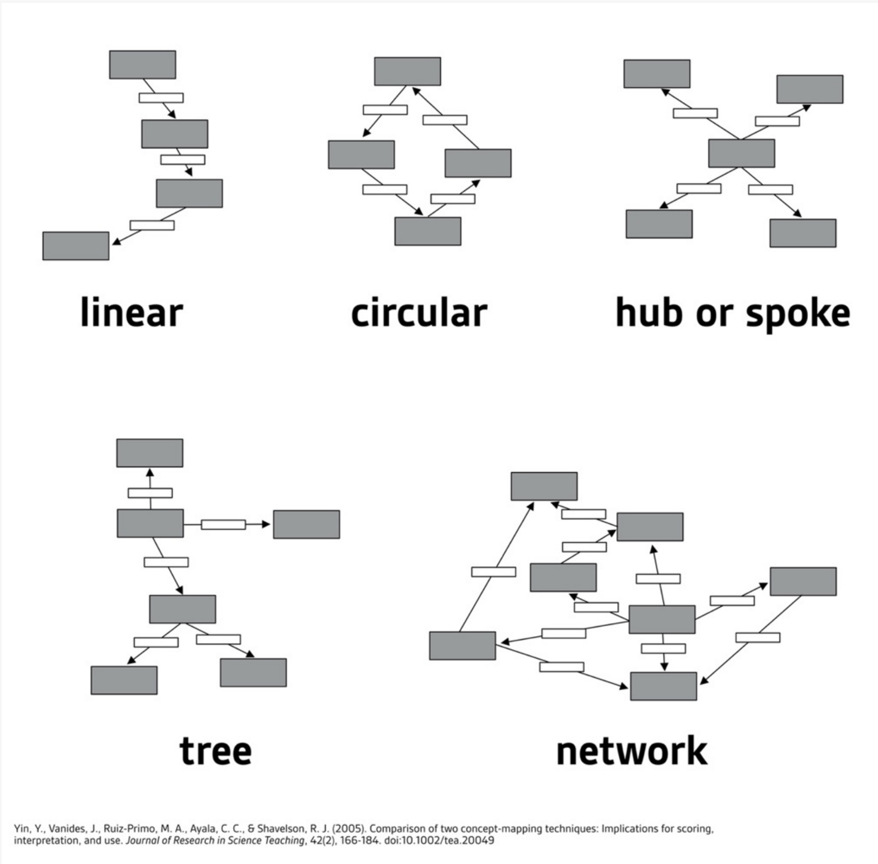
Table 13*: Criteria and Instructor uses for scoring concept maps*
(C = Content, S = Structure, macro level)

Criterion		individual		ratio	rubric	qualita-tive	combi-nations
		binary	scale				
concept maps	quality (C)	1 (0.2%)	1 (0.2%)		120 (21.8%)	25 (4.5%)	2 (0.4%)
	structural category (S)				42 (7.3%)		
	path lengths (S)	1 (0.2%)	8 (1.5%)	8 (1.5%)	1 (0.2%)		1 (0.2%)
Combined criteria and ratios	links to concepts (S)			4 (0.7%)			
	density (S)			15 (2.7%)			
	ratio of links to crosslinks (S)			4 (0.7%)			
	Extensive-ness (S)			3 (0.5%)			
	EntropyAvg (C)			1 (0.2%)			

Holistic content criteria: A frequent instructor use is to holistically assess the concept map with respect to defined quality criteria. Most often, this is done with the help of a scoring rubric that defines criteria and levels for scoring, such as comprehensiveness (complete and broad definition of subject), organization (systematic arrangement of concepts), and correctness (logic and facts; Besterfield-Sacre et al., 2004).

Holistic structure criteria: Researchers have distinguished different structural categories of concept maps (Kinchin et al., 2000): spoke structures with a core concept in the middle and the other concepts connected to it, chain structures with sequentially linked concepts, and net structures with a large variety of connections at various levels. It is further possible to interpret these structures in terms of learning: spoke structures indicate rote learning, chain structures indicate goal-directed learning or non-learning, and net structures indicate expert knowledge or meaningful learning (Hay & Kinchin, 2006; Hay et al., 2008). Yin et al. (2005) added circular structures with feedback loops and tree structures, where linear chains have additional branches (Fig. 57).

Fig. 57: Structural categories of concept maps (Yin et al., 2005)



In addition to these aforemetioned structural categories, it is also possible to base structural scoring of holistic concept maps on the length of paths (distance). In graph theory, distance is defined as the number of links between two concepts on the shortest path (Benjamin et al., 2015). As concept maps might include paths with very different distances, instructors and researchers need to define which distances they want to consider, e.g., the longest distance, known as the diameter (Ifenthaler, 2010b), or the average distance (Ley et al., 2011; Siew, 2018).

Combining different criteria: There are a range of approaches that combine different criteria. An example of such a combined criterion is to create a ratio of concepts to links, often interpreted as a measure of connectedness (Brakoniecki & Shah, 2017; Hao et al., 2010; Mavers et al., 2002).

10.3.6 Visual Features Criteria for Scoring Concept Maps

Few concept map scoring methods examine criteria related to visual features. Two criteria were found in our systematic literature review: additional resources added to concept maps (e.g., photos; 4 papers or 0.7%) and meaningful use of design features in concept maps (e.g., colors; 7 papers or 1.3%). For example, each additional multimodal resource added to concept maps can be scored for relevance based on a predefined scale (Schacter et al., 1997).

10.3.7 Creation Criteria for Scoring Concept Maps

Only a few studies use criteria related to creation processes, even though data on these creation processes can be automatically collected via digital concept mapping tools. Basic descriptive creation criteria include tracking the amount of time students spent creating their concept maps (4 papers or 0.7%) or how often students used the help or hint functionality (3 papers or 0.5%, e.g., Anohina-Naumeca, 2015). We found little research on concept map creation processes using log files or other forms of sequential data (9 papers or 1.6%). The rare exceptions are based on sequential pattern mining (Chiu & Lin, 2011), think-aloud data (Ghani et al., 2017), discourse analysis (Roth & Roychoudhury, 1994; Schwendimann & Linn, 2016), proposition generation rate (speed of constructing propositions; Yin et al., 2005), or identifying proposition generation strategies (Yin et al., 2005). Dias et al. (2019) proposed a promising approach to analyze construction processes for concept maps. Finally, a concept mapping assessment tool described by Anohina-Naumeca et al. (2011) specified each task's difficulty and used these degrees of difficulty in calculating scores (3 papers).

10.3.8 Frames of Reference and Associated Scoring Criteria to Compare Concept Maps

In addition the identified instructor uses and kinds of criteria for scoring concept maps, our framework also distinguishes different frames of reference. A frame of reference refers to a preference by instructors to use a specific type of comparison (Fischbach et al., 2015):

- descriptive (describing, but not comparing concept maps),
- individual (comparing concept maps by the same student from different points in time to assess learning gains),
- social (comparing concept maps by different students),
- expert (comparing student maps to expert maps, also called criterion maps), or
- group (not comparing individual concept maps, but combining them or taking the means, so that individual differences are averaged out)

Scores were often averaged to investigate group differences (362 papers or 65.8%) rather than describe individual concept maps (21 papers or 3.8%). However, social (111 papers or 20.2%), individual (85 papers or 15.5%), and expert frames of reference (76 papers or 13.8%) were also common. Frequently, papers apply several frames of references at once: for example, they might describe individual changes between pre- and post-intervention concept maps along with calculating group values like mean scores.

Content criteria: Many of the content criteria mentioned so far are applicable to different frames of reference, for example learner and expert concept maps. Thus, scoring consists of comparing how well componential or holistic criteria from one concept map match those from the other map. For example, Ruiz-Primo et al. (2001)'s "convergence score" is the ratio of propositions in a learner's concept map that match propositions from an expert concept map.

Structural criteria: Several identified criteria explicitly target comparative frames of reference, particularly with respect to the structural mode. Our systematic literature review identified considerable research on formulas to calculate the structural similarity of concept maps (35 papers, 6.4%) or create a joint representation (modal map, 14 papers, 2.5%), mostly using digital concept mapping tools. The majority of similarity criteria were used in an expert (17 papers, 3.1%), social (5 papers, 0.9%), or individual frame of reference (5 papers, 0.9%). Modal maps are typically used in a group frame of reference (10 papers, 1.8%). Four families of structural criteria can be identified:

- First, some criteria are based on the union and intersection of pairs of concept maps. The most frequent measure is the closeness index C by Goldsmith et al. (1991). It compares a student's concept map with an expert's concept map according to "the degree to which a concept has the same neighbors in two different networks" (Acton et al., 1994, p. 306), with values ranging between 0 (no similarity) and 1 (identical concept maps).
- Second, some criteria are based on the correspondence between learner and expert concept maps. For example, Eckert (1998) suggested different versions of a measure called the "correspondence coefficient", which is based on comparing which concepts are connected and not connected in learners' and experts' concept maps.
- Third, some criteria are based on the distance between pairs of concepts. Relevant algorithms use pathfinder analyses (Schvaneveldt et al., 1989) or multidimensional scaling (Wilson, 1996) to visualize similarities between concept maps.
- Fourth, a so-called "modal map" aggregates the most frequent propositions across all individual concept maps (Fürstenau & Trojahner, 2005). However, a problem with modal maps is their artificial character (Fürstenau & Trojahner, 2005): they represent the most common propositions, but were not created by any participant as such. Thus, an important measure is to calculate the percentage of propositions from a given participant's concept map that is present in the modal map ("Abbildungsleistung"; Fürstenau & Trojahner, 2005; Ley et al., 2012).

Scoring concept maps created collaboratively by several learners: concept maps are increasingly used in collaborative settings. Although the majority of papers examined concept maps that were created individually (294 papers, 63.9%), 10.4% of papers (48) report results from collaborative concept mapping, and 5.9% (27 papers) combine individual and collaborative concept mapping. 91 papers (19.8%) do not provide details about the type of concept mapping activity. Collaborative learning is based on social constructivist theory, and visualization methods like concept maps have been found to be highly effective in collaborative settings (Chen et al., 2018a). Research on collaborative learning has grown in recent years, particularly driven by a larger interest in social aspects of learning (Basque & Lavoie, 2006). For example, Stoyanova and Kommers (2002) and Nomura et al. (2014) described studies in which students first create an individual concept map, then collaborate with others to create a group concept map, and finally create another individual concept map again after this collaboration. Such an approach makes it possible to score concept maps at the individual level, the social level, at the level of interactions between individual and social learning (Khamesan & Hammond, 2004).

Changes across multiple concept maps over time: When students create multiple concept maps at different points of time, changes between earlier and later concept maps by the same learner can be scored. A typical approach is to consider which elements in a concept map remain when comparing pre- and post-instructional tests (Bernd et al., 2000; França et al., 2004) or to score categories of changes between two maps by the same student at different points in time (5 papers or 0.9%; Martin et al., 2000; Deshpande & Ahmed, 2019; McGowen & Davis, 2019).

Critiquing or extending concept maps: Critiquing or extending concept maps is valuable for constructing knowledge (Shen, 2010), but is rarely explored in papers that score concept maps. Only 36 papers (7.8%) describe a setting in which learners extend concept maps they have created in the past, and only 4 papers (0.9%) describe critiquing concept maps created by other learners. 18 papers (3.9%) describe having learners extend concept maps created by themselves and other learners.

10.3.9 Contexts of Scoring Concept Maps

In this section, we present the domains, levels of education, details of concept mapping tasks, and cognitive processes evaluated with concept maps (RQ 3). Table 14 provides an overview of the domains of knowledge and learners' levels of education addressed in the papers.

***Table 14**: Contextual dimensions of papers that score concept maps*

Contextual dimension	Studies	% of studies
Domains		
Natural sciences (total)	245	53.2%
Mathematics	10	2.1%
Computer sciences	32	7.0%
Physics	34	7.4%
Chemistry	30	6.5%
Earth & environmental sciences	45	9.8%
Biological sciences	76	16.5%
Other natural sciences	18	3.9%
Engineering	36	7.8%
Medicine	60	13.0%
Social sciences (total)	61	13.3%
Psychology	8	1.7%
Economics & business	10	2.2%
Educational sciences	35	7.6%
Other social sciences	8	1.7%
Humanities	15	3.3%
General knowledge	7	1.5%
Not provided	31	6.7%
Levels of education		

Early childhood (0-6 years old)	5	1.1%
Primary education (6-11 years old)	26	5.7%
Lower secondary education (12-15 years old)	50	10.9%
Upper secondary education (16 years old and above)	44	9.6%
Bachelor's level or equivalent	176	38.3%
Master's level or equivalent	20	4.3%
Doctoral level or equivalent	1	0.2%
Professional	33	7.2%
Retired	2	0.4%
Combinations (total)	35	7.4%
Bachelor & professional	9	2.0%
Bachelor & master	6	1.3%
Lower & upper secondary	4	0.9%
Other combinations	16	3.5%
Not provided	68	14.5%

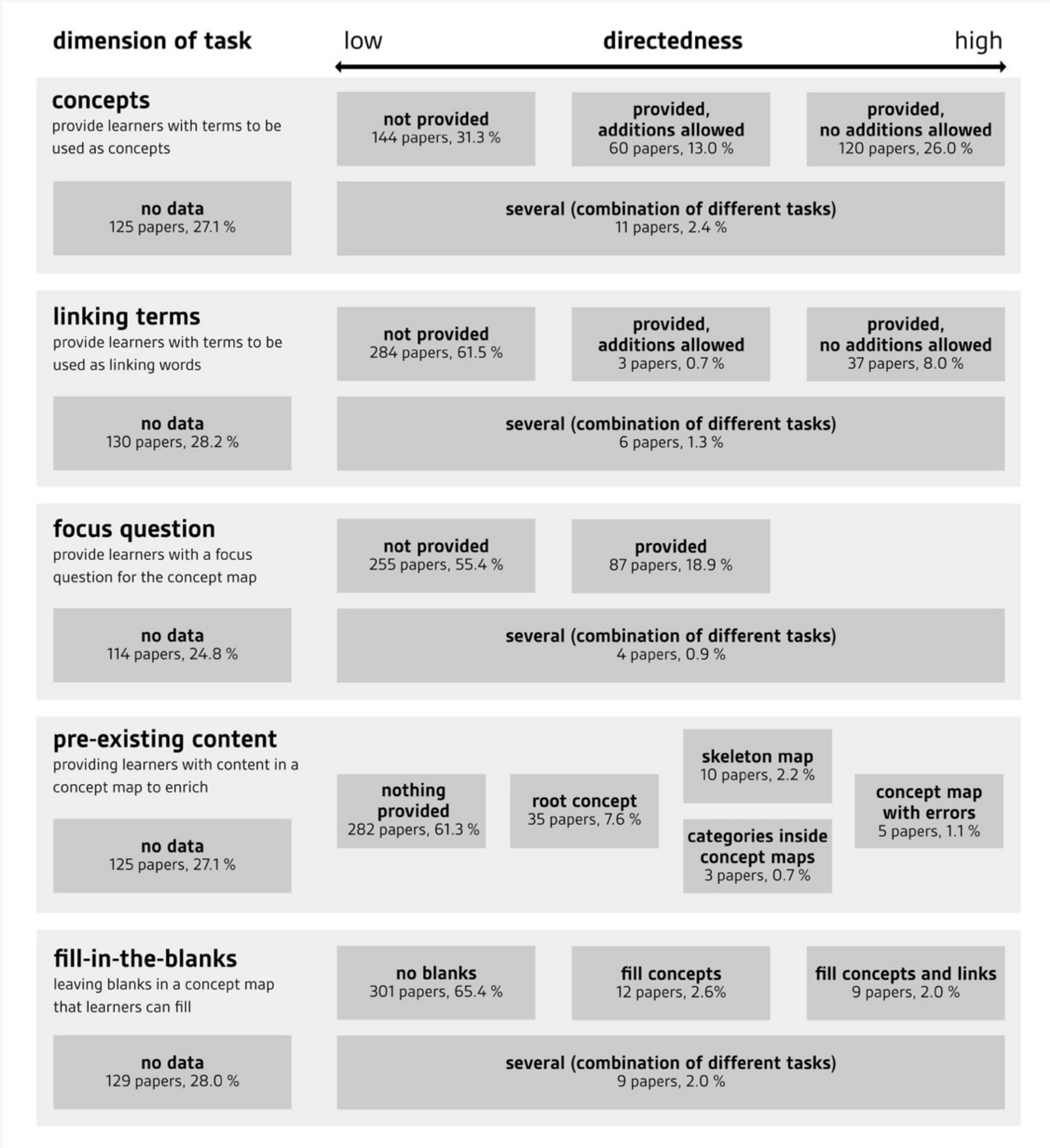
***Note**: Percentages are rounded to one decimal point and do not add up to 100% due to rounding errors.*

First, regarding the domains, scoring concept maps is an established assessment method in the natural sciences (53.2% of papers), most notably in biology (16.5%), earth & environmental sciences (9.8%), and physics (7.4%). Other important domains include the social sciences (13.3%), especially education, as well as medicine (13.0%), and engineering (7.8%). Thus, scoring concept maps for assessment purposes is well-established in a broad range of domains.

Second, regarding levels of education, the vast majority of studies include participants on bachelor's (38.3%), lower secondary (10.9%) or upper secondary level (9.6%). Participants from at the professional level are also common (7.2%). However, we found relatively little research with participants from the primary level (5.7%), early childhood (1.1%) and retired participants (0.4%), and no research from non-tertiary post-secondary fields (e.g., vocational training). These results mirror the strong emphasis on concept mapping in secondary and tertiary education.

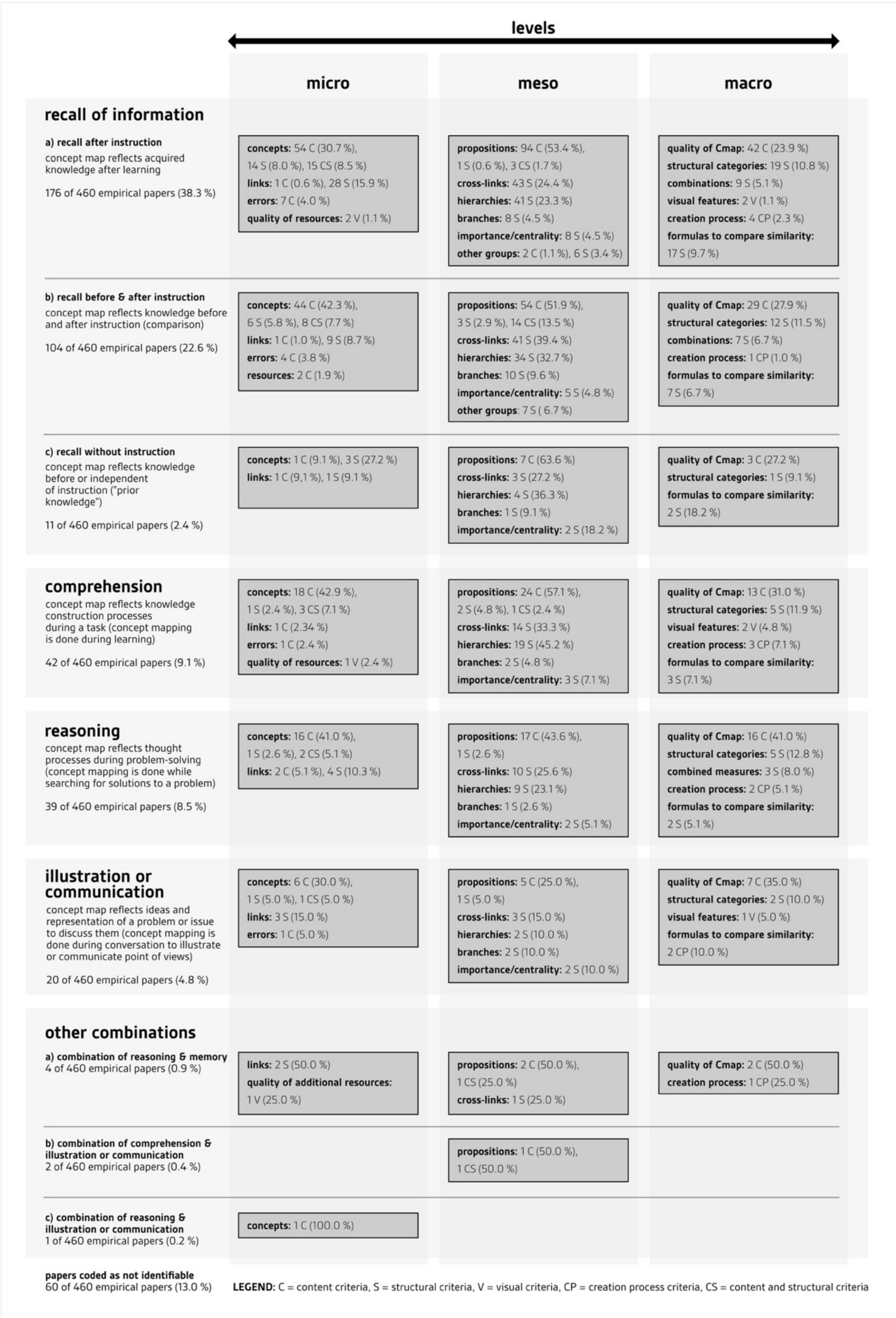
Third, regarding the concept mapping tasks, the majority of papers that score concept maps use low-directed concept mapping tasks (cf. Fig. 58). Across all criteria, low-directed tasks were the most frequent category, reflecting not providing any concepts (31.3%), linking terms (61.5%), focus question (55.4%), or other pre-existing content (61.1%). A smaller share of papers described high-directed approaches, mostly providing learners with concepts (26%) without allowing for additions by the learners themselves. Other concept mapping tasks are quite rare, in particular fill-in-the-blank activities (2.6% for fill-in-the-concepts, 2.0% for fill-in-the-concepts-and-links), providing learners with predefined concept map content to be enriched (7.6% provide root concepts, 2.2% skeleton maps, 1.1% concept maps containing errors, 0.7% specified containers to hold particular categories of concepts), or using distractor terms (4 papers or 0.95%). Furthermore, only a few papers systematically explore the impacts of low- vs. high-directed concept mapping tasks on concept map scores by comparing several approaches.

***Fig. 58**: concept mapping tasks used to score concept maps*



Fourth, regarding the cognitive processes (Fig. 59) assessed when scoring concept maps, papers predominantly use concept mapping to measure recall of information after instruction (38.3%) or both before and after instruction (22.6%). Other uses are to measure comprehension of material (9.1%, when concept mapping is done while working on the material), reasoning (8.5%, when concept mapping is done while working on solving a problem), or communication & illustration of ideas (4.3%, when concept mapping is done to first synthesize ideas or opinions about a topic and then discuss them with other people). The componential and holistic criteria for scoring concept maps identified in our comprehensive framework are evenly distributed across the different cognitive processes, indicating their versatility for scoring concept maps for various purposes.

***Fig. 59**: Criteria used to score concept maps representing different cognitive processes*



10.3.10 Addressing individuality in concept maps

Closely related to the differences between concept mapping tasks is the question of which level of standardization of concept maps is appropriate for a particular objective. One of the difficulties in scoring categories of concept map structure is that concept maps are highly individual. The more a concept mapping task allows for such individuality, the more challenging it is to score (Himangshu & Cassata-Widera, 2010), particularly with automatic scoring approaches. We found three main approaches to address this individuality:

- **Adapting the concept mapping task**: One approach is to limit the range of individuality, e.g., by providing learners with a list of concepts or linking labels they can select from. However, such an approach changes the nature of a concept mapping task: it lowers the cognitive load required to perform the task, but also constrains the amount of reflection learners have to do (Jonassen et al., 1997). Whether these constraints are unwanted, acceptable, or beneficial depends on what researchers and instructors want to use concept maps to find out.
- **Using a criterion-based frame of reference**: Another approach is to use a criterion-based frame of reference by defining an expert concept map as an idealized representation of a topic. However, such an approach also comes at a cost. For example, it is questionable whether such an ideal representation of any topic exists (Jonassen et al., 1997). Expert maps are typically created by either an instructor, an individual external expert, or several external experts (either in collaborative work, in which they have to agree on one map, or by combining their individual maps into a single one; Ruiz-Primo & Shavelson, 1996). However, given the nature of concept maps as active re-representations, concept maps by different experts do not always overlap, indicating that substantial variability exists in expert maps (Ruiz-Primo & Shavelson, 1996; Acton et al., 1994).
- **Standardizing concept maps**: A third approach is to standardize concept maps during scoring. One such standardized tool is to apply categories concepts and link labels (instead of the original labels) to facilitate comparison when students use different terms for similar content. For example, content categories can be used to redraw student maps with standardized terms (e.g., equating the terms "employee" and "worker"; Freeman & Urbaczewski, 2002). Such an approach allows learners to use the terms they prefer, but facilitates comparisons between learners. Similar approaches exist for structural criteria. It might be difficult to determine a concept map's structure category because, for example, students might arrange concepts in a tree-like concept map in a way that makes it look similar to a network-like concept map. Buhmann and Kingsbury (2015) proposed a method to standardize the structure of concept maps by, first, redrawing them without any content, and second, rearranging the branches following specified rules.

10.4 Discussion

Scoring for knowledge assessment means analyzing documents created by learners in order to infer the state of knowledge in their minds (Ruiz-Primo, 2004). When concept maps are used for this purpose, particular criteria are interpreted in light of a particular question (e.g., a research question or an educational assessment objective). Thus, researchers and instructors need a thorough understanding of which criteria can be applied to meet which objectives and how these criteria can be interpreted. The present systematic literature review found a variety of criteria used to score concept maps and proposed a framework to systematize them. In this section, we first discuss how our framework extends prior work. Second, we identify research gaps that are worth investigating in future research. Third, we discuss our results on the contexts of scoring concept maps.

Advancing concept map scoring with concept map scoring dimensions: Our comprehensive framework of criteria for scoring concept maps (cf. Fig. 56) both builds on and extends prior work. A particular advantage is that it explicitly distinguishes between three dimensions:

- Regarding *instructor uses*, we build on others' work distinguishing between qualitative and quantitative approaches (e.g., Anohina & Grundspenkis, 2009; Dixon, 2014; Keppens & Hay, 2008; Petrović et al., 2013). Instructors can use the four different instructor uses to make an informed decision about their scoring methodology. Thus, individual scoring is appropriate when each instance of a criterion should be considered in its own right (either in binary form by counting valid instances or using a scale to reflect more fine-grained differences in quality). Ratios or formulas are appropriate when different criteria are to be combined into a single metric. Rubric-based scoring is appropriate when all instances of a measure should be assessed together. Finally, qualitative interpretation is an option when a subjective assessment is needed.
- Regarding *levels*, our comprehensive framework proposes positioning criteria on a continuum from the micro to macro level. Micro- and meso-level criteria are componential, while macro-level criteria are holistic. When applying several componential criteria simultaneously to assess the quality of a concept map, scores from these individual componential criteria can be combined into a scoring scheme (e.g., component scoring; Strautmane, 2012). These scoring schemes need to be explicit regarding why particular criteria are chosen and how these criteria should be weighted. A prominent example of combining componential criteria into a scoring scheme is the component scoring method introduced by Novak and Gowin (1984). It uses componential criteria on the micro (categories of concepts, i.e., examples) and meso levels (propositions, hierarchical levels, crosslinks), but carefully theorizes on how to interpret them and which weight they each should have. For example, Novak and Gowin (1984, p. 107) state that crosslinks "signal possibly important integrative reconciliations and may therefore be better indicators of meaningful learning than are hierarchical levels" and suggest they should "receive 2 or 3 times the points". Thus, distinguishing between criteria on different levels can help other researchers understand one's scoring choices, which is of critical importance because scores fundamentally affect the interpretation of a concept map.

- Regarding *modes*, we follow proposals by others (e.g., Strautmane, 2012) in distinguishing between content and structural criteria. However, we extend this distinction by identifying the scoring of visual features and concept map creation data as additional possibilities. As will be shown in the following section, these areas constitute research gaps and have direct implications for instructors.
- Regarding *frames of reference*, most other frameworks of concept map scoring also mention comparing learner concept maps to expert concept maps (Constantinou, 2002; Ruiz-Primo & Shavelson, 1996; Venkatesan et al., 2017). Our proposal builds on this work, presenting two additional advantages. It enables discussion of other frames of reference besides comparing a learner's concept map to an expert concept map, such as the individual frame of reference for formative assessment. Furthermore, similar to the frameworks proposed by Anohina and Grundspenkis (2009) and Strautmane (2012), including frames of reference as a dimension allows for better describing the relationship between a criterion and how it is used. For example, a limited number of criteria can only be examined in a comparative frame of reference (e.g., the closeness index), but many can be applied across a range of frames of reference.

10.4.1 Research Gaps in Scoring Visual Features and Process Data

Second, our comprehensive framework of criteria for scoring concept maps identified research gaps in concept map scoring that are worth exploring. In contrast to the large variety of content and structure criteria, we found a limited number of scoring approaches regarding visual features and the processes involved in creating concept maps. However, the demand for visual design features in digital concept mapping tools is high (Rohles et al., 2019), and technical capabilities exist to record and analyze process data, e.g., using log files (Miller et al., 2008). The prominence of visual features in digital concept mapping tools indicates that the lack of application of such features in scoring should be addressed. What is their role in the creation of concept maps (e.g., simply for decoration, as a motivation enhancer, better structuring of concept maps, encoding meaning through the use of shapes, colors, etc.)? We think these questions deserve discussion, research, and explicit recommendations by instructors because they could have a profound impact on the fairness of scores. An example would be a concept map where learners have to distinguish between concepts describing chemical and physical processes. If one learner used colors and another used propositions to create this distinction, their scores would differ unless visual features are considered in scoring. Thus, instructors could provide rules for the use (or non-use) of design features in concept mapping or ask learners to make their choices explicit (e.g., with a legend). Likewise, scoring process data based on log files created while learners construct their concept maps might yield interesting results. For example, a formative assessment system might recognize a decreasing proposition generation rate, which could indicate that learners do not know how to continue (with the system potentially reacting accordingly). Concept maps could thus become "history-enriched digital objects" (Hollan et al., 2000, p. 187) that capture not only the final state but also the history of their creation. Potentially, such data could provide researchers and instructors with valuable information to score, such as when learners build similar maps by following very different approaches (with some learners build their maps in a linear way and others going back for more revisions). Regarding structural criteria, like the link to concept ratio, prior research suggests that a middle range should be considered ideal (Ifenthaler, 2010a). Research might investigate similar questions for process data regarding concept map creation: Is the number of steps learners need to reach a specific state for a concept map indicative of the quality of learning that occurred? Admittedly, this is a question that would need thorough investigation, but it illustrates the many areas of research that must still be considered to advance concept map scoring.

10.4.2 Criteria to Score Concept Maps in Context

Third, beyond creating a comprehensive framework of criteria used to score concept maps, the present systematic literature review also investigated the context of concept map scoring along four dimensions: domains, levels of education, concept mapping tasks, and cognitive processes. The results suggest that concept maps are scored in a broad range of domains and levels of education. Likewise, concept mapping tasks show a broad variation, albeit with a strong focus on low-directed tasks. These concept mapping tasks constrain learners' reflection processes to a much lesser extent than high-directed tasks (Jonassen et al., 1997) and are thus typically less correlated with other achievement measures (Himangshu & Cassata-Widera, 2010). However, low-directed tasks have a different focus than high-directed tasks: For example, they act as a re-representation of learners' cognitive structures (Ifenthaler, 2010b) and allow individual misconceptions to be identified and addressed (Himangshu & Cassata-Widera, 2010). Thus, it is vital that researchers and educators carefully decide which concept mapping task is appropriate for their objective and learn to "read" concept maps in order to make informed scoring decisions. Our comprehensive framework of criteria used to score concept maps provides a foundation for these readings.

Our systematic literature review identified a large number of cognitive processes that are investigated with concept maps. Although the majority of empirical papers explored recall of information (independently of instruction, before instruction, or both), with concept maps as a re-representation of cognitive structures (Ifenthaler, 2010b), a significant number examined reasoning about a problem, comprehension while working on materials, or illustrating and communicating an idea. Our results indicate that the identified criteria to score concept maps do capture these different cognitive processes, but might be interpreted in different ways for different purposes. For example, propositions in concept maps created in a recall task might reflect the differentiation of concepts in cognitive structures (Jonassen et al., 1997). However, in a comprehension task, where learners create a concept map to make sense of instructional materials, propositions might indicate processes of creating and adapting a mental model to align existing and new information (Ifenthaler, 2010b).

10.4.3 Limitations

There are three limitations to our systematic literature review that should be noted. First, we excluded papers that were not in English or German. Although we cannot rule out that more criteria for scoring concept maps have been explored in other languages, we are confident that other researchers could adopt and extend our comprehensive framework to include criteria explored in other languages' research traditions.

Second, working on our comprehensive framework revealed a theoretical issue that might be worth addressing: the distinction between links and propositions. Most papers we found followed the definition of a proposition as two concepts connected by a link (Ruiz-Primo, 2004), for example "Romans" + "*are important for*" + "Latin" (link in italics; from Novak & Gowin, 1984, p. 84). In these cases, the number of links equals the number of propositions. However, it has also been pointed out that propositions can be made up of more than two concepts (Novak & Gowin, 1984; Novak, 2010), for example "Latin" + "*is*" + "basis" + "*for*" + "romance languages" (links in italics; from Novak & Gowin, 1984, p. 84). In these cases, the definition of a proposition is a semantic one close to the idea of the "basic unit of meaning in a concept map" (Ruiz-Primo & Shavelson, 1996, p. 570). We coded criteria as "propositions" when the paper made clear that it was interested in this semantic unit, regardless of which term it used to refer to these units of meaning (e.g., "link", "relationship", "connection"). Although we double-coded our results and discussed disagreements, we cannot rule out that different interpretations of the link-proposition distinction are possible. However, we think that this issue highlights two important considerations: (a) instructors should be careful to teach students how to build propositions (e.g., aim to create simple ones), and (b) researchers should carefully decide and report how they approached this issue in their scoring.

Third, the large number of criteria used to score concept maps poses questions about their effectiveness. Scoring effectiveness is related to questions of validity or reliability, which have been the focus of a number of studies (Shavelson et al., 2005; McClure et al., 1999; Schau et al., 2001) and meta-reviews (Himangshu & Cassata-Widera, 2010). Scoring effectiveness is also related to the question of which criterion is most appropriate in a specific context, such as a particular domain, research question, or assessment objective. Although we have included information and suggestions related to the effectiveness of different criteria in different contexts at various places in the present review and the supplementary guidelines S3 (https://rohl.es/dissertation), we acknowledge that the effectiveness of scoring concept maps was not our main concern. However, we think that our comprehensive framework provides a valuable foundation for future studies on the effectiveness of scoring concept maps due to its systemization of relevant dimensions. Future studies on the effectiveness of concept map scoring could systematically explore the different dimensions of our comprehensive framework (for example, compare individual, ratio, and rubric-based scoring of the same measure). Alternatively, future studies on scoring effectiveness could involve instructors directly by examining which criteria they consider appropriate for a particular context.

10.4.4 Conclusion

The present systematic literature review explored criteria used to score concept maps as a means of knowledge assessment. A systematic literature review with specified search criteria was conducted to ensure the inclusion of relevant publications that score concept maps. 550 studies in English and German were found eligible for inclusion.

Three dimensions were identified that distinguish criteria used in concept map scoring. First, four distinct instructor uses apply to scoring concept maps: individual scoring (counting and awarding points for each instance of a criterion), rubric-based scoring (awarding a certain number of points by judging the level of a criterion based on predefined criteria), ratios or formulas (awarding points based on a defined calculation rule), and qualitative interpretation. Second, kinds of criteria cover the level and mode. The level of analysis specifies the granularity used to explore concept maps. It is based on a continuum spanning from individual components (e.g., concepts or links, "the micro level") to group components (e.g., propositions or hierarchical levels, "the meso level") and ultimately to the holistic evaluation of a complete concept map ("the macro level"). In addition, different modes were identified within the broader dimension of different kinds of criteria. Here, content, structure, visual features, and process data can be scored. Third, criteria are used with different frames of reference, such as describing individual maps, calculating group metrics (e.g., mean values), and comparing maps. When comparing concept maps, the frame of reference might be individual (comparing maps by the same learner across different points in time), social (comparing maps by different learners), and expert (comparing learner maps to a reference/expert map). Most criteria were found to apply to different frames of references, but some criteria specifically reflect particular frames of references.

A comprehensive framework of criteria for scoring concept maps was built to integrate these dimensions and present the identified criteria in a detailed, systematic way. The comprehensive framework can help researchers and instructors interpret and make informed choices about scoring concept maps. Furthermore, the comprehensive framework helped to identify research gaps and theoretical issues that can contribute to advancing concept map scoring.

10.4.5 Acknowledgment

This research was funded by the SCRIPT, an institution of the Luxembourgish government to enhance education. Furthermore, we thank our independent double-coders Jannis Rutschmann and Romain Cirelli for their valuable contribution to checking and enhancing the quality of our framework, and Keri Hartman for her thorough copy-editing of our manuscript. Finally, we thank the reviewers and editors involved in the creation of the systematic literature review for their indispensable suggestions and feedback.

PART V:
Impact of UX on Digital Concept Mapping

11 Creating Positive Learning Experiences With Technology: A Field Study on the Effects of User Experience for Digital Concept Mapping

Abstract

Learning and assessment are increasingly mediated by digital technologies. Thus, learners' experiences with these digital technologies are growing in importance, as they might affect learning and assessment. The present paper explores the impact of user experience on digital concept mapping. Specifically, it builds on user experience theory to explain variance in the intention to use digital concept mapping tools and in concept map-based assessment scores. Furthermore, it identifies fulfillment of psychological needs as an important driver of positive experiences. In a field study in three schools and a university (N = 71), we tested two prototypes of a digital concept mapping tool on computers and tablets. We found that user experience is a significant factor explaining variance in intention to use. User experience also explained variance in three out of four concept mapping scores on tablets, potentially related to the lower pragmatic quality of the tablet prototypes. Fulfillment of psychological needs strongly affected perceptions of different qualities of user experience with digital concept mapping. These results indicate that user experience needs to be considered in digital concept mapping to provide a positive and successful environment for learning and assessment. Finally, we discuss implications for designers of digital learning and assessment tools.

11.1 Introduction

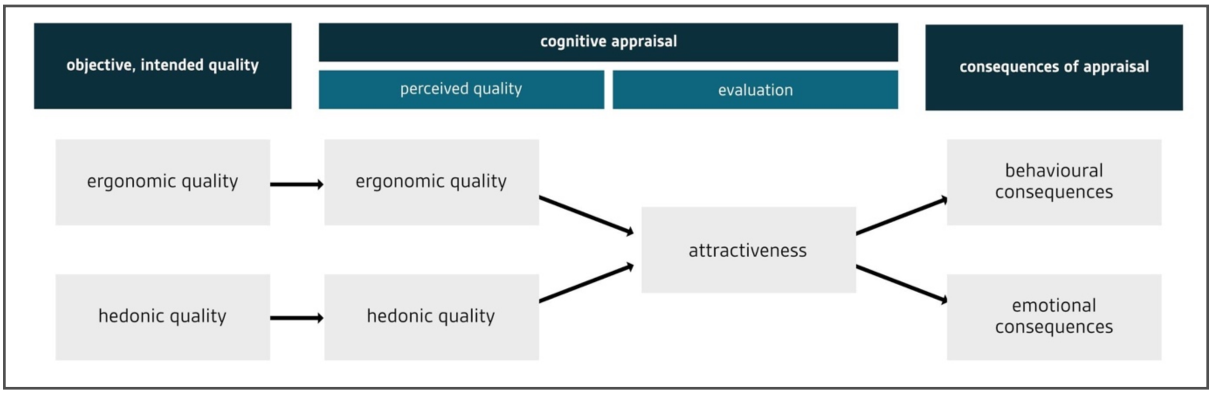
The field of education is increasingly addressing "21st century digital skills" like critical thinking and problem-solving (van Laar et al., 2017). Concept mapping is a promising method for acquiring these skills (Novak, 2010). Furthermore, increasing attention is being paid to the subjective experiences that shape learning, like engagement, interests, motivation, or needs (Norman & Spohrer, 1996; Reigeluth et al., 2017), leading to a greater focus on the learner. For instance, the fulfillment of psychological needs has been found to impact learning and assessment (Evans et al., 2012; Masters et al., 1979; Pekrun, 2006; Tien et al., 2018). When it comes to designing digital tools for education, the concept of "user experience" has emerged to capture such subjective experiences with technology (Bargas-Avila & Hornbæk, 2011).

The purpose of this paper is to empirically investigate the role of user experience (UX) in digital concept mapping, particularly its relationship with psychological needs, intention to use, and scores on a concept map-based assessment. In this way, the paper contributes to establishing UX as a phenomenon of interest in research on digital education, particularly with respect to the role of UX in knowledge assessment. Such assessments can be a high-stakes operation for learners, because scores could directly impact their future educational trajectories. Thus, it is vital to ensure that UX aspects do not influence learners' future opportunities.

11.2 Current State of Research

In the last two decades, the impact of technology on human beings has been increasingly discussed from a user experience (UX) perspective. There are many models of UX, such as the one suggested by Hassenzahl (2001) (see Fig. 60). This model provides a good foundation for investigating the role of UX in assessment because it includes consequences of UX and outlines how characteristics of a product (e.g., a digital education technology) relate to characteristics of the experience. According to this model, digital products have pragmatic and hedonic qualities. When users interact with a product, they build a subjective impression of these pragmatic and hedonic qualities, and these are referred to as the pragmatic and hedonic dimensions of UX. The pragmatic dimension refers to instrumental or ergonomic aspects, termed the "do-goals" of interaction, and covers usability components like ease of use or efficiency (Hassenzahl, 2008). The hedonic dimension refers to the fulfillment of deeper psychological needs (like feeling competent or feeling stimulated), known as "be-goals" (Hassenzahl, 2008). Users form an overall judgement of the attractiveness of the product based on their impressions of its quality. This judgement has consequences for their behavior (e.g., use of the technology) and experience (e.g., emotional reactions). Recent research explores whether so-called eudaimonic quality constitutes a third dimension of user experience (Mekler & Hornbæk, 2016; Mekler & Hornbæk, 2019). Eudaimonic quality refers to the development of one's full potential (Huta & Ryan, 2010) and is thus particularly important in the field of education.

Fig. 60: *Model of user experience suggested by Hassenzahl (2001)*



In the following sections, we will first examine research on antecedents of UX in digital education, namely psychological needs, before turning to the outcomes of UX in digital education, namely intention to use and learning success.

11.2.1 Psychological Needs as Drivers of Experience

Psychological needs play an important role in creating positive experiences (Hassenzahl et al., 2010; Tay & Diener, 2011). Psychological needs are defined as "basic requirements for the functioning of an organism" (Desmet & Fokkinga, 2020, p. 2) and are a substantial source of motivation (Levesque et al., 2004). Several theories have been developed that identify specific psychological needs among humans. For example, Abraham H. Maslow assumed a hierarchical ordering of human needs (Maslow, 1943). However, empirical research does not support the notion of a universal hierarchical ordering of needs (Desmet & Fokkinga, 2020). Self-determination theory (Deci & Ryan, 2000; Orkibi & Ronen, 2017), which identified autonomy, competence, and relatedness as basic psychological needs, has received support from a range of studies (Levesque et al., 2004; Oostdam et al., 2018). Sheldon et al. (2001) synthesized research on human needs into a list of ten basic needs: self-esteem, autonomy, competence, relatedness, pleasure/stimulation, physical thriving, self-actualizing/meaning, security, popularity/influence, and money/luxury. A range of design methods for needs fulfillment have been developed on the basis of this synthesis of needs (Diefenbach et al., 2014b; Desmet & Fokkinga, 2020; Lallemand, 2015).

Numerous studies have demonstrated the importance of needs in learning and assessment, e.g., in the context of physical education (Katartzi & Vlachopoulos, 2011), learning to play a musical instrument (Evans et al., 2012), avoiding maladaptive behaviors in school (Oostdam et al., 2018), or promoting psychological well-being (Orkibi & Ronen, 2017; Tay & Diener, 2011). Needs are important for experiencing an activity as pleasurable and meaningful (Desmet & Fokkinga, 2020). These positive emotions can significantly enhance learning and assessment (Masters et al., 1979; Tien et al., 2018; Yang et al., 2013) in areas such as creativity tasks (Fredrickson, 1998; Isen et al., 1985; Lyubomirsky et al., 2005) and decision-taking tasks (Carpenter et al., 2013). Interest in psychological needs in design has recently been growing, particularly regarding how to design for motivation, engagement, and well-being through fulfillment of psychological needs (Peters et al., 2018; Wannheden et al., 2021). Thus, identifying how digital education tools contribute to such need fulfillment is vital when education is increasingly digitalized.

11.2.2 Intention to Use

The success of digital products depends on users' willingness to use them. The question of which aspects determine whether a person will adopt a given technology has been addressed from various angles (Alexandre et al., 2018), such as the technology acceptance model tradition (Davis et al., 1989; Venkatesh & Davis, 2000; Venkatesh, 2000; Venkatesh & Bala, 2008). In line with the growing recognition of the value of experience (Newman & Blanchard, 2016; Pine & Gilmore, 1998; Solis, 2015), research on technology adoption increasingly addresses the UX perspective (Alexandre et al., 2018; Hornbæk & Hertzum, 2017). Although the boundaries and relations between UX-based acceptance theories and other theories like TAM are not always clear (Hornbæk & Hertzum, 2017; Alexandre et al., 2018), it is generally agreed that UX can contribute to explaining what drives intention to use a technology. There are two reasons for this. First, the strong rooting of UX in psychological factors such as the aforementioned psychological needs helps to clarify how these factors contribute to technology adoption (Alexandre et al., 2018; Hornbæk & Hertzum, 2017). UX models like the one by Hassenzahl (2001) are rarely used to predict experiences and outcomes (Hornbæk & Hertzum, 2017), but exploring such alternative models of intention to use has been encouraged (Šumak et al., 2011). Second, UX places a strong emphasis on the role of different dimensions of experience, such as the pragmatic and hedonic dimensions (Hassenzahl, 2008), for technology adoption. Thus, a UX-based perspective on intention to use could provide recommendations for designing digital products and services that are likely to be adopted by their envisioned users (Hornbæk & Hertzum, 2017). Recently, researchers have started to include experience into technology acceptance models (Ahmad et al., 2021; McLean et al., 2018). This paper contributes to this research by providing a perspective grounded in UX theory: It provides a broad picture of the impacts of experience by incorporating antecedents (i.e., psychological need fulfillment) and outcomes (i.e., scores in assessment, see following) in the analysis.

11.2.3 User Experience in Learning and Assessment

Research on the impact of user experience on learning and assessment has often focused on pragmatic aspects, especially usability. Usability impacts learning success (Tselios et al., 2008) and assessment (Tselios et al., 2001; Weinerth et al., 2013). This effect is frequently discussed in terms of cognitive load theory, with the suggestion that it reduces so-called extraneous cognitive load (due to design aspects such as usability issues) so that learners can invest their mental resources in task-relevant activities (Amadieu et al., 2015; Hollender et al., 2010; Sweller, 2010).

Although UX includes these pragmatic considerations, the concept of UX also encompasses the hedonic dimension. Hedonic aspects like joy and motivation are also likely to influence learning and assessment (Hollender et al., 2010). For example, positive emotions enhance learning (Masters et al., 1979; Tien et al., 2018) and heighten learners' willingness to invest mental resources in learning (Efklides et al., 2006). Numerous studies found relations of UX and learning, for example with serious games (Espinosa-Curiel et al., 2020). Thus, digital learning and assessment tools should impact learning not only from the perspective of usability and cognitive load, but also by creating a positive, engaging environment.

The present study focuses on digital concept mapping as a case study for investigating the role of UX. Concept mapping (Novak & Gowin, 1984) is a method of visually representing relationships within complex knowledge. It consists of concepts (in the form of shapes) connected by labelled links (arrows). Meaningful units of at least two concepts and links are known as propositions (Shavelson et al., 2005). Concept mapping is a very promising case study for evaluating the role of UX in digital education for several reasons. First, only a few studies systematically investigate UX in concept mapping (e.g., see Weinerth et al., 2014a for usability in concept mapping). Recently, Pinandito et al. (2020) investigated acceptance of a particular concept mapping system (called Kit-Build) in the framework of technology acceptance. They found that perceived enjoyment and ease of use significantly predict students' evaluations of a systems' usefulness, providing evidence to the importance of UX in concept mapping. However, no holistic exploration of the role UX plays in concept mapping has been conducted. Second, concept mapping is a promising approach for addressing contemporary challenges in education like systems thinking (Assaraf & Orion, 2005; Brandstädter et al., 2012; Cox et al., 2019) or assessing complex knowledge structures (Shavelson et al., 2005). As cognitive structures are not directly observable, concept mapping allows learners to create a visualization of their understanding of a topic (Ifenthaler, 2010b). Concept maps can be assessed with respect to a variety of different aspects, such as their comprehensiveness, organization, or correctness (Besterfield-Sacre et al., 2004). Third, concept mapping is a complex task where learners need to constantly elaborate and reflect on the propositions they create (Amadieu et al., 2009; Sanchiz et al., 2019). Digital concept mapping tools have the potential to facilitate these processes (Hwang et al., 2012) and enable the creation of more complex concept maps that better reflect learners' knowledge (Brandstädter et al., 2012). However, these potential benefits depend on the qualities of the digital concept mapping tool itself, or in other words, how users experience it.

11.2.4 Research Questions

The purpose of this paper is to examine how user experience impacts digital concept mapping. In particular, it addresses the relations among UX, fulfillment of psychological needs, intention to use, and assessment scores for digital concept mapping. The research questions (RQ) were defined as follows: How do psychological needs affect UX in digital concept mapping (RQ 1)? How does UX affect intention to use digital concept mapping (RQ 2)? How does UX affect scores in digital concept mapping (RQ 3)?

In line with the role of psychological needs in creating positive experiences, we hypothesized that need fulfillment would significantly predict the pragmatic and hedonic dimensions of UX:

Hypothesis 1: The fulfillment of psychological needs significantly predicts the pragmatic and hedonic dimensions of UX.

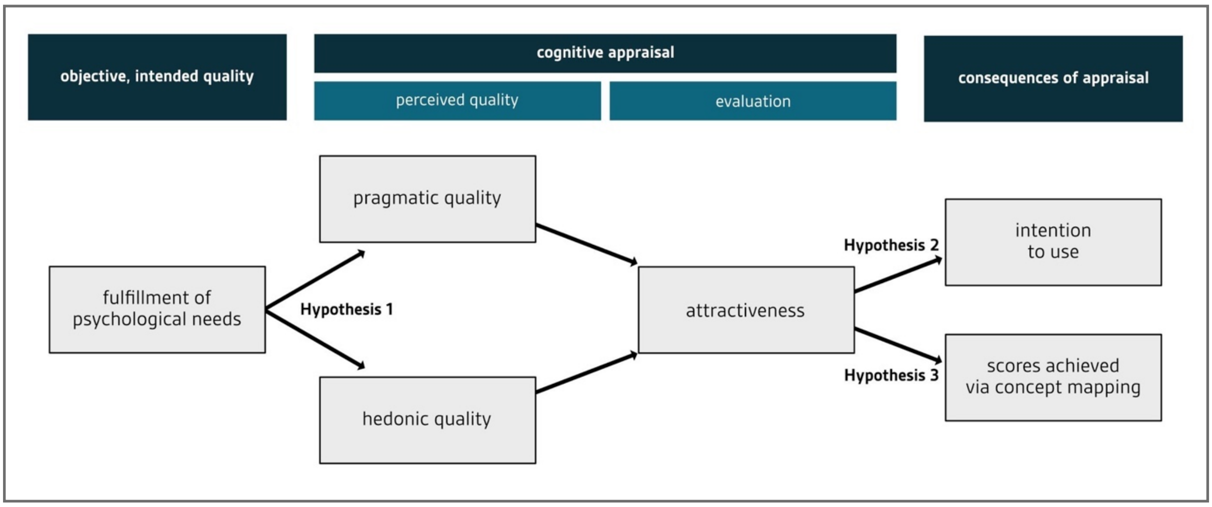
Furthermore, we hypothesized that attractiveness would explain variance in intention to use and concept mapping scores. With respect to intention to use, we assumed that learners would be more willing to use a digital tool with a higher UX because it allows them to reach their pragmatic and hedonic goals. With respect to concept mapping scores, we assumed that a digital tool with a higher UX would lead to reduced extraneous cognitive load (pragmatic aspects; Sweller, 1994; Sweller et al., 2011) and enhanced motivation (hedonic aspects). These advantages would allow learners to create higher-quality concept maps:

Hypothesis 2: Attractiveness significantly predicts intention to use.

Hypothesis 3: Attractiveness significantly predicts concept mapping scores.

An overview of the hypotheses is represented in Fig. 61:

Fig. 61: *Hypotheses of the present study, adapted from Hassenzahl (2001)*



11.3 Methods

We aimed to examine an ecologically valid context and conducted a field experiment in educational institutions across Luxembourg. Four classes in three different schools and a group of university students participated in the study ($N = 71$[29], see Table 15).

Table 15: *Participants and settings of the study*

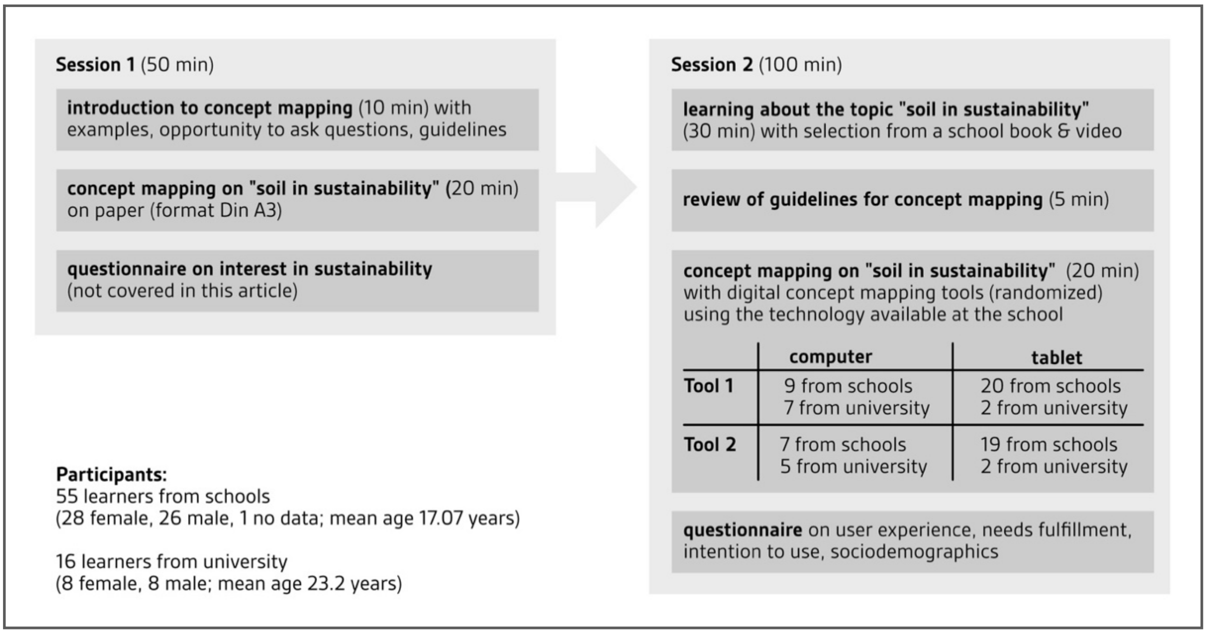
School	Grade	Age	N	Setting
Secondary school – technical track	3e (11th grade)	$M = 17.20$ yr; $SD = 1.612$ yr	10 male 5 female	Computer, class
Secondary school – academic track	1e (13th grade)	$M = 18.29$ yr; $SD = 0.463$ yr	7 male 14 female 1 no data	Tablet, class
Secondary school – academic track	4e (10th grade)	$M = 15.50$ yr; $SD = 0.535$ yr	6 male 2 female	Tablet, remote
Secondary school – academic track	4e (10th grade)	$M = 15.50$ yr; $SD = 0.699$ yr	3 male 7 female	Tablet, remote
University	Bachelor: 10 Master: 4 PhD: 2	$M = 23.19$ yr; $SD = 4.339$ yr	8 male 8 female	Computer, class: 9 Tablet, class: 3 Computer, remote: 3 Tablet, remote: 1

The study was part of a research project investigating the role of UX in digital concept mapping. The project obtained ethical approval from the Ethics Review Panel of the University of Luxembourg (ERP 18031). Strict ethical guidelines of informed consent by participants and (for minors) their parents were

[29] Data from 30 additional participants was collected but excluded from the study because these participants served as a pre-test, used another tool, or were absent in one of the sessions.

applied. Participants received compensation of € 50 (university participants) or were released from regular instruction for participation (school participants). The study took place in two sessions, usually at an interval of 3-7 days. Materials from the sessions were linked using a subject-generated identification code. The identification codes mentioned in this article were re-coded to safeguard anonymity. Fig. 62 provides an overview of the study setup.

***Fig. 62**: Setup of the study*



11.3.1 Pre-tests and Study Setting

Our study setup originally intended to incorporate digital concept mapping in both sessions. All procedures and materials were pre-tested with a class of 7 learners (6 male, 1 female, mean age 17.4 years). The pre-test revealed that not all schools were able to provide digital devices for two sessions. Furthermore, the learners had difficulties learning both the method and a particular concept mapping tool simultaneously. Consequently, we conducted paper-based concept mapping for the first session as a baseline measurement.

In Session 1, learners received a standardized introduction to concept mapping with guidelines (Novak, 2010) and created a paper-based concept map of their prior knowledge on the topic of “soil in sustainability” (about 20 minutes). In Session 2 (100 minutes), participants learned about the study topic “soil in sustainability” (30 minutes) and created a digital concept map (about 20 minutes). This topic was chosen because we expected a low level of systematic prior knowledge, as this topic is rarely discussed in detail in the media or the school curriculum. The learning material consisted of a selection from a school textbook (Hoffmann, 2018) and a video (Streckenbach, 2012) by the renowned German Institute for Advanced Sustainability Studies (IASS). These materials were chosen for their quality (as verified by an external expert and via specific questions in the questionnaire) as well as their use of different input modalities (visual and verbal information) to support different processes in working memory (Baddeley, 2000). All materials were available in the three most important languages in the multilingual country in which the study took place. After the learning phase, the concept mapping guidelines were reviewed and remained available to learners during the concept mapping activity (about 20 minutes). Finally, data on UX, need fulfillment, sociodemographic background, and intention to use was collected with a questionnaire (described in Section 11.3.3).

As the study intended to achieve high ecological validity, learners participated with the technologies available at their schools (tablets or computers) and in the same teaching conditions as regular instruction (in-person in the classroom or remotely during Covid-19 lockdowns). Care was taken to keep the study conditions identical by strictly standardizing all procedures (e.g., with the help of video recordings for remote participants). Furthermore, we performed a manipulation check to verify which contextual factors impacted UX (described in Section 11.3.4).

To achieve our aim of conducting the study in a setting with high ecological validity, we randomly assigned participants to one of two fully functional concept mapping tools. The two tools were developed to focus on different points along the continuum of pragmatic and hedonic characteristics (Hornbæk & Hertzum, 2017): Tool 1 was optimized primarily for pragmatic UX, while Tool 2 was optimized for both pragmatic and hedonic UX. However, as we will outline in Section 11.3.4, the prototypes did not create systematically different UX. Thus, we have included detailed descriptions of the prototypes in Appendix G.

11.3.2 Concept Mapping

In this study, we elected to provide participants with a list of suggested terms and a focus question ("Soil – an existential resource?") to improve the accuracy of participants' propositions (Brandstädter et al., 2012; Ruiz-Primo, 2004). This list of 31 concepts and ten links was extracted from a reference concept map created by an independent domain expert. Learners were allowed to add their own terms. Furthermore, we included two distractors that were not necessary to describe the topic (Strautmane, 2012).

The quality of participants' concept maps was scored with a scoring rubric developed by Besterfield-Sacre et al. (2004) and a reference concept map reflecting expert knowledge of the topic. Rubrics describe criteria and levels of performance and are well-established in education (Brookhart, 2013). The rubric by Besterfield-Sacre et al. (2004) evaluates three dimensions: comprehensiveness (how well the concept map explains the topic), organization (how interconnected the concept map is), and correctness (whether the concept map contains misconceptions). Previous research has successfully applied the rubric to studying sustainability (Watson et al., 2016). The original scoring rubric was adapted to the topic of "soil in sustainability" and converted into a scale by allowing mid-values (e.g., between 1 and 2) (see Appendix H). Furthermore, we gave concept maps that completely failed to describe the topic a score of 0.

Participants' paper concept maps (Session 1) and digital concept maps (Session 2) were independently analyzed by two researchers. The two researchers then discussed their ratings and reached agreement. These scores were then summed up to calculate a global score (Watson et al., 2016). Finally, we subtracted the scores from Session 1 from the scores from Session 2 to arrive at a score reflecting the difference between the concept maps created on paper (independent of any instruction and user experience) and digitally created concept maps (reflecting newly acquired knowledge from the instruction and potential influences of user experience).

11.3.3 Measurements

We applied the User Experience Questionnaire (UEQ; Laugwitz et al., 2008) to measure UX. The UEQ is based on the model of user experience by Hassenzahl (2001) but seeks to capture a balance of pragmatic and hedonic aspects (Laugwitz et al., 2008). Thus, the UEQ is a good fit for our research questions, because both pragmatic and hedonic aspects are important for digital concept mapping tools (Rohles et al., 2019). The UEQ consists of three subscales for pragmatic quality and two subscales for hedonic quality, with four items each. Furthermore, it includes six items measuring the overall attractiveness of the product. Attractiveness is assumed to depend on the ratings on the pragmatic and hedonic scales (Laugwitz et al., 2008). In addition to the UEQ, we included an open question asking for participants' feedback and ideas regarding the concept mapping tool.

We applied a scale developed by Lallemand and Koenig (2017) based on Sheldon et al. (2001) to measure need fulfillment (see Table 16). In addition, each learner evaluated the importance of each of the seven needs for concept mapping on a 5-point Likert scale (Lallemand & Koenig, 2017).

***Table 16**: Overview of psychological needs used in the present study (Sheldon et al., 2001, p. 339; Lallemand & Koenig, 2017)*

Need	Definition	Example item: During this interaction, I felt…
Autonomy and independence	"Feeling like you are the cause of your own actions rather than feeling that external forces or pressures are the cause of your actions".	… that my actions were based on my interests.
Competence and effectiveness	"Feeling very capable and effective in your actions rather than feeling incompetent or ineffective".	… that I was successfully completing tasks.
Relatedness and belongingness	"Feeling that you have regular intimate contact with people who care about you rather than feeling lonely and uncared for."	… a sense of contact with other people in general.
Pleasure and stimulation	"Feeling that you get plenty of enjoyment and pleasure rather than feeling bored and understimulated by life."	… that I was experiencing new activities.

Security and control	"Feeling safe and in control of your life rather than feeling uncertain and threatened by your circumstances."	… that things were structured and predictable.
Popularity and influence	"Feeling that you are liked, respected, and have influence over others rather than feeling like a person whose advice and opinions nobody is interested in."	… that I was a person whose opinion counts for others.
Self-actualizing and meaning	"Feeling that you are developing your best potentials and making life meaningful rather than feeling stagnant and that life does not have much meaning."	… my actions were with purpose.

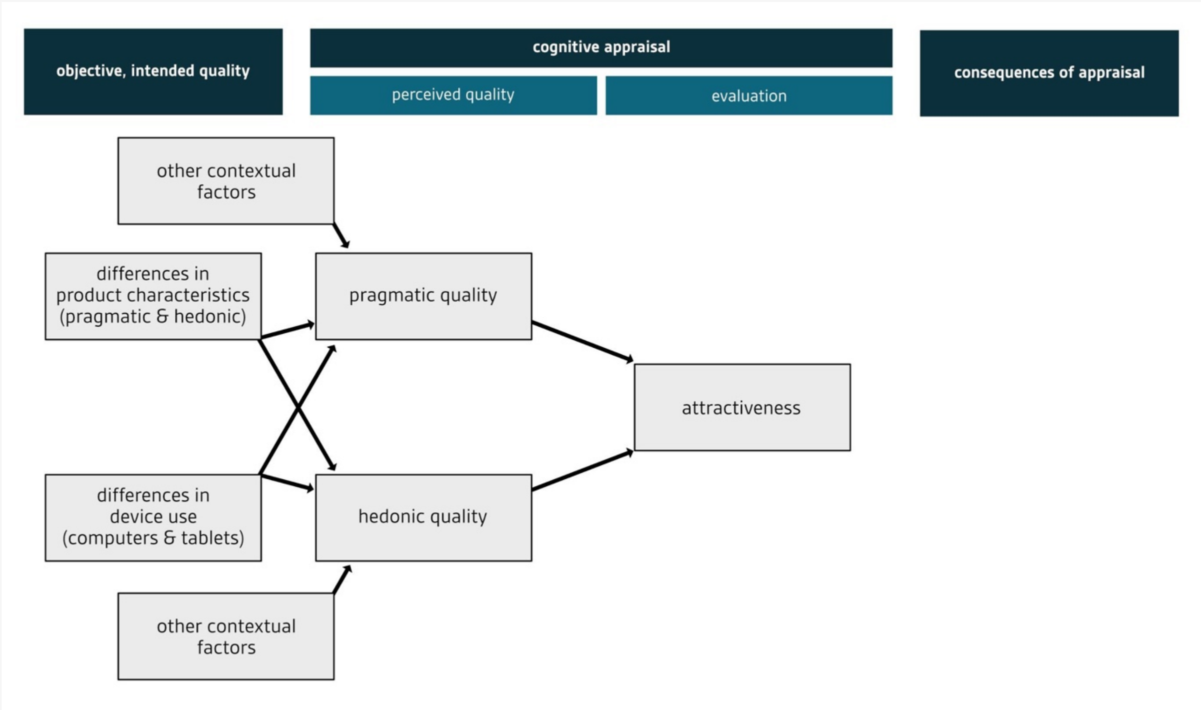
Finally, we captured intention to use with a single item "I would use the tool if it were available" on a 5-point Likert scale. Participants in the in-person sessions answered on paper, participants in the remote sessions answered via an online survey. All statistical analyses were performed using SPSS version 27. All reported confidence intervals (95% bias-corrected and accelerated) and standard errors are based on 1,000 bootstrapped samples.

We calculated reliability of the standardized scales (UEQ and need fulfillment) using McDonald's ω (Danner et al., 2016; Hayes & Coutts, 2020; McDonald, 1999). ω was calculated with the SPSS macro available from Hayes and Coutts (2020). Reliability of the UEQ items was very high: pragmatic quality ($\omega = 0.87$), hedonic quality ($\omega = 0.89$), and attractiveness ($\omega = 0.90$). Reliability of the need fulfillment was as follows: autonomy and independence ($\omega = 0.70$), competence and effectiveness ($\omega = 0.85$), relatedness and belongingness ($\omega = 0.77$), pleasure and stimulation ($\omega = 0.76$), security and control ($\omega = 0.74$), influence and popularity ($\omega = 0.61$), self-actualizing and meaning ($\omega = 0.68$). We consider most of these values acceptable and return to the remaining issues in Section 11.4 when we discuss the study's limitations.

11.3.4 Manipulation Success Check of User Experience Scores

Before analyzing the data, we performed several manipulation success checks (see Fig. 63).

***Fig. 63**: Manipulation checks for the present study, adapted from Hassenzahl (2001)*



The first set of manipulation checks sought to identify which contextual factors significantly impacted UX. Given the high ecological validity we sought to achieve, these factors could relate to the tool, namely version (Version 1 vs. Version 2) and device (computer vs. tablet), as well as to other contextual factors, namely subsample (university vs. school) and setting (classroom or remote instruction during Covid-19 lockdowns). Thus, we first inspected boxplots of the UEQ results to identify outliers that might have an overly strong influence on the mean scores. Three potential outliers scored very low on the UEQ. However, when inspecting their concept maps, feedback, and scores on the other variables, the UEQ perfectly reflected their experience, as the three participants had severe problems with the tools. We concluded that these outliers do represent valid experience data, and thus decided to leave them in our data set. Second, we used histograms and Shapiro-Wilk tests (Ghasemi & Zahediasl, 2012; Shapiro & Wilk, 1965) to check the normal distribution assumption for the UEQ dimensions attractiveness, pragmatic, and hedonic quality. Attractiveness deviated from normal on computers, $W(28) = 0.900$, $p = 0.011$, and pragmatic quality deviated from normal in several settings, namely on tablets, $W(43) = 0.941$, $p = 0.028$, among school students, $W(55) = 0.948$, $p = 0.019$, and in in-person teaching settings, $W(49) = 0.936$, $p = 0.011$. Thus, and thirdly, we performed four independent t-tests using bootstrapping, assuming unequal variances (Field, 2018; Zimmerman, 2004) (see Table 17). As an estimate of effect size, we calculated Cohen's *d* (Cohen, 1988; Cohen, 1992) using pooled standard deviations.

***Table 17**: t-tests of different factors on UEQ subscales*

Group	Pragmatic dimension	Hedonic dimension	Attractiveness
tool version (Tool 1 vs. Tool 2)	$t(65.669) = 0.110$ $p = 0.913$ $d = 0.026$	$t(67.414) = 0.208$ $p = 0.836$ $d = 0.050$	$t(64.470) = -0.064$ $p = 0.949$ $d = -0.015$
device (computer vs. tablet)	$t(62.918) = 2.971$ $p = 0.004$ $d = 0.702$	$t(52.244) = -0.622$ $p = 0.537$ $d = -0.155$	$t(61.619) = 1.162$ $p = 0.250$ $d = 0.277$
population (university vs. school)	$t(21.453) = 0.804$ $p = 0.430$ $d = 0.252$	$t(20.964) = 0.283$ $p = 0.780$ $d = 0.091$	$t(22.547) = 0.618$ $p = 0.543$ $d = 0.186$
setting (remote vs. in-class)	$t(52.540) = -1.732$ $p = 0.089$ $d = -0.401$	$t(45.138) = -0.002$ $p = 0.999$ $d = 0.000$	$t(45.368) = -0.556$ $p = 0.581$ $d = -0.136$

The t-tests revealed that, contrary to our expectations, the different tool versions did not evoke significantly different user experiences. Interestingly, despite the lack of significant differences in user experience between the tool versions, the participants' feedback on Tool 1 reflected aspects that were addressed in Tool 2 (see Appendix I for a detailed discussion). However, the device used for the concept mapping task had a significant impact. The pragmatic dimension of user experience was significantly higher on computers ($M = 1.26$, $SD = 0.92$) than on tablets ($M = 0.56$, $SD = 1.05$). The difference (0.70, +/- 0.45) was significant, $t(62.918) = 2.97$, $p = 0.004$, and represented a medium-sized effect of $d = 0.70$ (Cohen, 1988). The differences on the scales for attractiveness (computers: $M = 0.92$, $SD = 1.16$; tablets: $M = 0.58$, $SD = 1.27$) and hedonic dimension (computers: $M = 0.24$, $SD = 1.32$; tablets: $M = 0.43$, $SD = 1.15$) were not significant (see Table 17). No other differences were found.

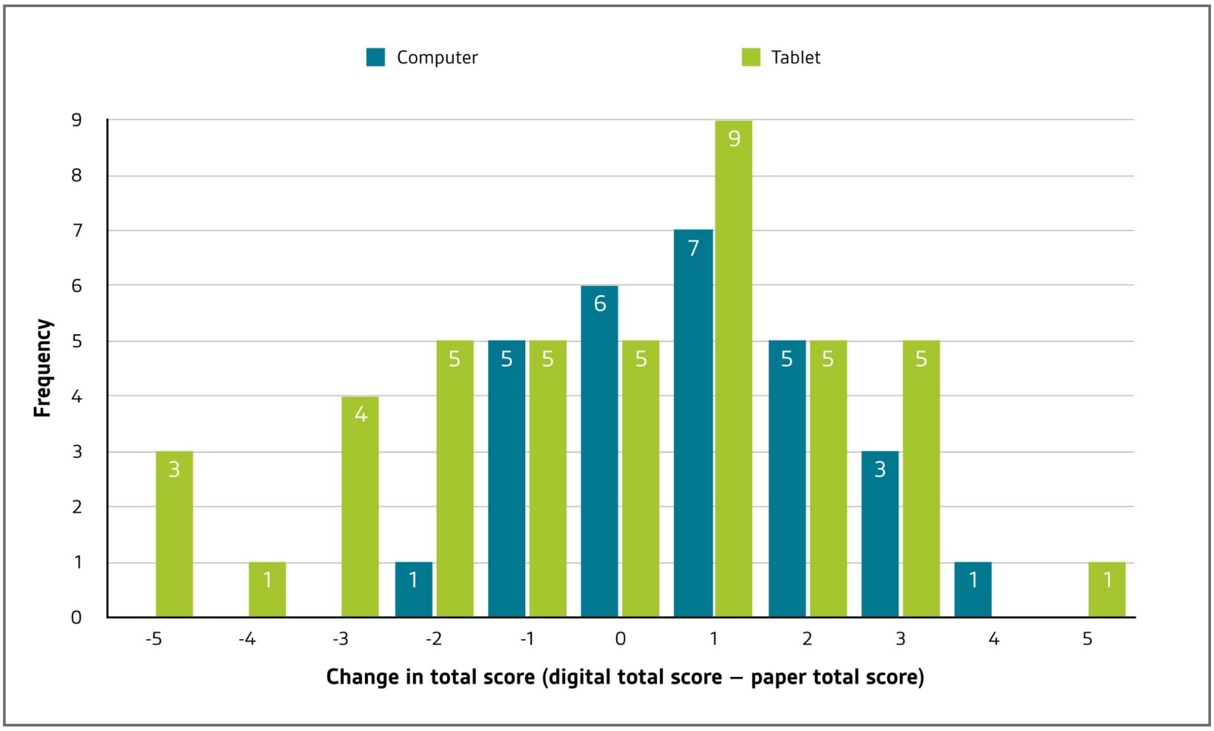
Table 18 provides descriptive statistics for the measured variables. Needs fulfillment and intention to use were relatively high, while concept map scores showed a normal distribution. Overall, the mean scores on the digital concept maps resembled those on the paper concept maps. However, when exploring the individual change scores (per participant), it became apparent that the majority of learners achieved higher scores on the digital concept maps, particularly on computers (see Fig. 64).

***Table 18**: Descriptive statistics for the variables in the present study*

Variable	Computer ($N = 28$)	Tablet ($N = 43$)
Needs fulfillment (0-5 scale)		
Autonomy & independence	$M = 3.67$, $SD = 0.75$	$M = 3.22$, $SD = 0.84$
Competence & effectiveness	$M = 3.34$, $SD = 0.93$	$M = 3.11$, $SD = 0.92$
Relatedness & belongingness	$M = 2.83$, $SD = 0.94$	$M = 2.48$, $SD = 1.02$
Pleasure & stimulation	$M = 3.13$, $SD = 0.83$	$M = 2.79$, $SD = 0.96$

Security & control	*M* = 3.46, *SD* = 0.74	*M* = 3.17, *SD* = 0.85
Influence & popularity	*M* = 2.96, *SD* = 0.76	*M* = 2.70, *SD* = 0.73
Self-realization & meaning	*M* = 3.48, *SD* = 1.00	*M* = 2.93, *SD* = 0.86
Global needs	*M* = 3.27, *SD* = 0.65	*M* = 2.93, *SD* = 0.73
Intention to use (0-5 scale)	*M* = 3.17, *SD* = 1.30	*M* = 2.93, *SD* = 1.19
Scores		
Comprehensiveness (0-3 scale)	*M* = 1.57, *SD* = 0.60 (Paper map: *M* = 1.42, *SD* = 0.47)	*M* = 1.70, *SD* = 0.64 (Paper map: *M* = 1.77, *SD* = 0.55)
Organization (0-3 scale)	*M* = 1.50, *SD* = 0.61 (Paper map: *M* = 1.25, *SD* = 0.40)	*M* = 1.51, *SD* = 0.81 (Paper map: *M* = 1.55, *SD* = 0.50)
Correctness (0-3 scale)	*M* = 1.66, *SD* = 0.61 (Paper map: *M* = 1.34, *SD* = 0.45)	*M* = 1.50, *SD* = 0.72 (Paper map: *M* = 1.56, *SD* = 0.47)
Holistic total score (0-9 scale)	*M* = 4.73, *SD* = 1.60 (Paper map: *M* = 4.02, *SD* = 1.04)	*M* = 4.47, *SD* = 1.94 (Paper map: *M* = 4.86, *SD* = 1.15)

Fig. 64*: Changes in total scores on computers (left) and tablets (right)*



Finally, to check whether hedonic and pragmatic UX predict attractiveness, we calculated two linear regression models. The results indicated that pragmatic and hedonic qualities of user experience significantly predicted attractiveness in both conditions (computers: $F(2, 25) = 73.874$, $p = 0.000$, tablets: $F(2,40) = 80.570$, $p = 0.000$). The overall fit of the models was very good (computers: $R^2 = 0.86$, tablets: $R^2 = 0.80$). The model parameters on computers (all $p = 0.000$) were $b = 0.55$ for pragmatic quality (SE 0.11; +/- 0.23) and $b = 0.57$ for hedonic quality (SE 0.07; +/- 0.15). The model parameters on tablets (all p = 0.000) were b = 0.45 for pragmatic quality (SE 0.11; +/- 0.11) and b = 0.668 for hedonic quality (SE 0.10; +/- 0.35). Therefore, we concluded that the UEQ reports UX as expected.

11.4 Results and Discussion

11.4.1 Research Question 1: Impact of Needs Fulfillment on Pragmatic and Hedonic UX

To examine the influence of need fulfillment on the pragmatic and hedonic subdimensions of UX (RQ 1), we calculated linear regression models with the fulfillment of all seven measured needs regressed on pragmatic (see Table 19) and hedonic UX (see Table 20). We checked each model for bias and regression assumptions as outlined in Appendix J.

The results indicated that autonomy and independence had the strongest explanatory power for positive UX in digital concept mapping, with respect to both the pragmatic (computers: 54.4%, tablets: 26.0%) and the hedonic dimension (computers: 23.8%, tablets: 32.8%). A good digital concept mapping tool allows learners to create concept maps without external help or training ("do-goal") and provides them with the functionalities they need to express themselves as desired ("be-goal"; Hassenzahl, 2008). These autonomy-supporting characteristics result in a positive UX. This interpretation is supported by the high explanatory power of fulfillment of need for security/control for pragmatic UX (computers: 52.6%, tablets: 37.8%), indicating that when learners feel in control of the interaction, they have a positive experience regarding the achievement of their "do-goals". It has been suggested that security and control should be considered a "deficiency need, i.e., a need that creates negative affect if blocked, but not necessarily strong positive feelings if fulfilled" (Hassenzahl et al., 2010, p. 358). Thus, we would expect security and control to explain variance in pragmatic UX but not hedonic UX. However, security/control also explained 37.8% of the variance in hedonic UX on tablets, although it was insignificant on computers. Potentially, the lower overall pragmatic quality of the tablet optimization led to lower fulfillment of "be-goals", but the better overall pragmatic quality of our computer prototypes had no positive impact on the experience of achieving "be-goals". However, we also note that the model with security/control predicting hedonic UX should be interpreted with caution because the assumption of homoscedasticity (Field, 2018) might not hold (see Appendix J).

***Table 19**: Explanatory power of need fulfillment on pragmatic UX*

Predictor of pragmatic UX	R^2	b	SE *b*	p
autonomy and independence	**Computers: 0.544** **Tablets: 0.260**	**Computers: 0.904 (+/- 0.482)** **Tablets: 0.633 (+/- 0.307)**	**Computers: 0.176** **Tablets: 0.184**	**Computers: 0.000** **Tablets: 0.000**

competence and effectiveness	**Computers: 0.363** **Tablets: 0.167**	**Computers: 0.599 (+/- 0.269)** **Tablets: 0.466 (+/- 0.382)**	**Computers: 0.162** **Tablets: 0.219**	**Computers: 0.001** **Tablets: 0.006**
relatedness and belongingness	Computers: 0.072 Tablets: 0.056	Computers: 0.263 (+/- 0.366) Tablets: 0.243 (+/- 0.304)	Computers: 0.204 Tablets: 0.148	Computers: 0.168 Tablets: 0.126
pleasure and stimulation	Computers: 0.085 **Tablets: 0.190**	Computers: 0.322 (+/- 0.541) **Tablets: 0.478 (+/- 0.316)**	Computers: 0.226 **Tablets: 0.166**	Computers: 0.132 **Tablets: 0.003**
security and control	**Computers: 0.526** **Tablets: 0.378**	**Computers: 0.903 (+/- 0.331)** **Tablets: 0.754 (+/- 0.247)**	**Computers: 0.175** **Tablets: 0.167**	**Computers: 0.000** **Tablets: 0.000**
influence and popularity	**Computers: 0.267** Tablets: 0.042	**Computers: 0.629 (+/- 0.385)** Tablets: 0.291 (+/- 0.512)	**Computers: 0.211** Tablets: 0.214	**Computers: 0.005** Tablets: 0.190
self-realization and meaning	**Computers: 0.155** **Tablets: 0.129**	**Computers: 0.361 (+/- 0.616)** **Tablets: 0.437 (+/- 0.369)**	**Computers: 0.267** **Tablets: 0.214**	**Computers: 0.038** **Tablets: 0.018**

Certain needs systematically explained variance in pragmatic UX, namely competence/effectiveness (computers: 36.3%, tablets: 16.7%) and self-actualizing/meaning (computers: 15.5%, tablets: 12.9%). Both needs also explained variance in hedonic UX, but only on tablets (18.0% and 22.6%, respectively). When a digital concept mapping tool allows learners to successfully express their cognitive structures (Ifenthaler, 2010b), they feel competent and realize their full potential, resulting in a positive UX. Mekler and Hornbæk (2016) reported correlations between pragmatic and eudaimonic qualities which might explain why the learning-related needs were particularly predictive of pragmatic UX.

Table 20*: Explanatory power of need fulfillment on hedonic UX*

Predictor of hedonic UX	R^2	b	SE b	p
autonomy and independence	**Computers: 0.238** **Tablets: 0.328**	**Computers: 0.856 (+/- 0.53)** **Tablets: 0.783 (+/- 0.249)**	**Computers: 0.285** **Tablets: 0.158**	**Computers: 0.008** **Tablets: 0.000**
competence and effectiveness	Computers: 0.069 **Tablets: 0.180**	Computers: 0.373 (+/- 0.57) **Tablets: 0.532 (+/- 0.338)**	Computers: 0.304 **Tablets: 0.209**	Computers: 0.177 **Tablets: 0.005**
relatedness and belongingness	Computers: 0.009 **Tablets: 0.119**	Computers: 0.130 (+/- 0.463)	Computers: 0.263 **Tablets: 0.165**	Computers: 0.640 **Tablets: 0.023**

		Tablets: 0.390 (+/- 0.311)		
pleasure and stimulation	**Computers: 0.188** **Tablets: 0.297**	**Computers: 0.684 (+/- 0.599)** **Tablets: 0.657 (+/- 0.247)**	**Computers: 0.290** **Tablets: 0.145**	**Computers: 0.021** **Tablets: 0.000**
security and control	Computers: 0.062 **Tablets: 0.378**	Computers: 0.445 (+/- 0.735) **Tablets: 0.829 (+/- 0.234)**	Computers: 0.317 **Tablets: 0.152**	Computers: 0.200 **Tablets: 0.000**
influence and popularity	Computers: 0.020 **Tablets: 0.124**	Computers: 0.247 (+/- 0.661) **Tablets: 0.553 (+/- 0.46)**	Computers: 0.328 **Tablets: 0.236**	Computers: 0.472 **Tablets: 0.021**
self-realization and meaning	Computers: 0.124 **Tablets: 0.226**	Computers: 0.455 (+/- 0.523) **Tablets: 0.636 (+/- 0.353)**	Computers: 0.216 **Tablets: 0.186**	Computers: 0.066 **Tablets: 0.001**

Turning to hedonic UX, the need for pleasure and stimulation significantly explained variance in hedonic UX (computers: 18.8%, tablets: 29.7%) and thus seems to be related to participants' "be-goals" (Hassenzahl, 2008). Interestingly, pleasure had greater explanatory power on tablets than on computers. Pleasure and stimulation also predicted variance in pragmatic UX (19.0%), but only on tablets. We hypothesize that this explanatory power on tablets might be related to the different style of interaction, which has been described as more enjoyable (Hwang et al., 2012). Thus, designing a tablet tool with a positive UX has the potential to better fulfil learners' needs for pleasure and stimulation. Computers, on the other hand, could be a more "neutral" device with a stronger focus on pragmatic qualities. Thus, impressions of need fulfillment might vary between computers and tablets, further indicating the need to optimize user experience for each device separately.

In summary, we found evidence supporting Hypothesis 1: Our results suggest that need fulfillment significantly explains variance in pragmatic and hedonic UX, although not universally for all needs and devices. This finding is further supported by the importance ratings participants gave each need for digital concept mapping (see Table 21). The most important needs for digital concept mapping are security/control, competence/effectiveness, pleasure/stimulation, autonomy/independence, and self-realization/meaning. These results can serve as a starting point for "compil[ing] a product-specific needs profile" (Desmet & Fokkinga, 2020, p. 11) for concept mapping. The social needs of relatedness/belongingness and influence/popularity were given lower importance ratings and played a smaller role in explaining variance in UX, likely due to the individual nature of the concept mapping setting in the present study. The results might be different for collaborative concept mapping activities (Khamesan & Hammond, 2004). Independent samples t-tests revealed no significant differences in the importance of psychological needs between devices.

***Table 21**: Descriptive statistics on the importance of needs*

Need	Computer	Tablet
Autonomy/independence	$M = 3.21$, $SD = 0.74$	$M = 2.95$, $SD = 0.94$
Competence/effectiveness	$M = 3.37$, $SD = 1.08$	$M = 3.30$, $SD = 0.71$
Relatedness/belongingness	$M = 2.25$, $SD = 1.08$	$M = 2.60$, $SD = 0.82$
Pleasure/stimulation	$M = 3.25$, $SD = 0.89$	$M = 3.14$, $SD = 0.97$
Security/control	$M = 3.46$, $SD = 0.64$	$M = 3.33$, $SD = 0.75$
Influence/popularity	$M = 2.46$, $SD = 1.10$	$M = 2.70$, $SD = 0.91$
Self-realization/meaning	$M = 3.11$, $SD = 0.88$	$M = 3.14$, $SD = 0.80$

11.4.2 Research Questions 2 and 3: Impact of User Experience on Intention to Use and Digital Concept Mapping Scores

To determine the impact of user experience on intention to use (RQ 2) and assessment scores (RQ 3), we calculated linear regression models with attractiveness predicting intention to use and the four assessment scores. We checked each model for bias and assumptions as outlined in Appendix J.

The results for intention to use (see Table 22) confirm that user experience is vital for acceptance of a digital product. The UX dimension of attractiveness significantly predicted 72.3% of intention to use on computers and 36.5% of intention to use on tablets. Thus, we found no evidence that would lead us to reject Hypothesis 2 and concluded that UX significantly impacts intention to use. Interestingly, the amount of variance explained by attractiveness is much higher on computers than on tablets. Potentially, the pragmatic issues on tablets impacted intention to use. Alternatively, there might be general differences in technology acceptance, with a specific group of users rejecting tablets for digital concept mapping in general (Amadieu et al., 2019).

Turning to the influence of attractiveness on concept map scores (Hypothesis 3), we found that attractiveness explained variance in changes in organization scores, changes in correctness scores, and changes in total scores, with small R^2 values ranging from 0.091 to 0.112 on tablets (see Table 22). The models for changes in comprehensiveness scores on tablets and the models for all change scores on computers were not significant, indicating the weak explanatory power of attractiveness. Thus, we concluded that the evidence for rejecting Hypothesis 3 is inconclusive: attractiveness significantly explains variance in three of the four scores on tablets, but does not explain variance in comprehensiveness scores or on computers.

Table 22: *Models using attractiveness as a predictor for the respective outcome variables*

Outcome	R2	b	SE b	p
Intention to use	**Computers: 0.723** **Tablets: 0.365**	**Computers: 0.906 (+/- 0.217)** **Tablets: 0.544 (+/- 0.218)**	**Computers: 0.111** **Tablets: 0.101**	**Computers: 0.000** **Tablets: 0.000**
Change in comprehensiveness scores	Computers: 0.011 Tablets: 0.063	Computers: -0.042 (+/- 0.150) Tablets: 0.163 (+/- 0.219)	Computers: 0.064 Tablets: 0.105	Computers: 0.600 Tablets: 0.104
Change in organization scores	Computers: 0.053 **Tablets: 0.091**	Computers: -0.116 (+/- 0.173) **Tablets: 0.198 (+/- 0.175)**	Computers: 0.084 **Tablets: 0.085**	Computers: 0.240 **Tablets: 0.049**
Change in correctness scores	Computers: 0.041 **Tablets: 0.109**	Computers: 0.109 (+/- 0.207) **Tablets: 0.233 (+/- 0.212)**	Computers: 0.101 **Tablets: 0.113**	Computers: 0.303 **Tablets: 0.031**
Change in total score	Computers: 0.002 **Tablets: 0.112**	Computers: -0.049 (+/- 0.287) **Tablets: 0.594 (+/- 0.563)**	Computers: 0.179 **Tablets: 0.278**	Computers: 0.828 **Tablets: 0.028**

One explanation for the low explanatory power of UX for concept map scores could be that the different qualities of UX do not impact concept map scores evenly. When pragmatic quality is low, learners might need to invest cognitive resources in using the tool instead of the task, in line with cognitive load theory (Sweller, 1994; Sweller et al., 2011). Interestingly, our results suggest that a threshold of pragmatic quality might exist, with pragmatic quality only impacting scores when it is below the hypothesized threshold. In line with this interpretation, UX had no explanatory power on computer versions of our tools, where the pragmatic quality was higher. Additionally measuring cognitive load might help to assess whether this interpretation holds (Amadieu et al., 2009).

Regarding hedonic quality, we think that it is too early to draw a conclusion. The theorized positive impact of hedonic quality might potentially develop over time, as higher engagement leads to a gradual improvement in scores. Furthermore, the hedonic qualities of our tools did not differ significantly and were largely in a medium range (Schrepp et al., 2017). Potentially, studies of repeated tool use or tools with higher overall hedonic qualities might be needed to uncover the impact of hedonic qualities on concept map scores. It is also possible that hedonic quality is related to learning-related outcomes other than assessment scores, such as completion rates.

11.4.3 Conclusion

As learning and assessment are becoming increasingly digitalized, it is vital to explore learners' experiences with these digital tools. The present paper, based on a field study in three schools and a university (N = 71), found that user experience (UX) significantly explained variance in intention to use a digital concept mapping tool. UX was also capable of explaining variance in some concept mapping scores. Furthermore, fulfillment of psychological needs was found to be an important driver of users' experience with this digital technology. Thus, UX is important for providing a positive and successful environment for digital concept mapping.

Our results have a range of implications beyond digital concept mapping. With respect to the design and evaluation of digital education products, our findings suggest that tools should be optimized for each particular technological context in order to provide an adequate user experience, just as educational tasks are adapted to the devices used (Mulet et al., 2019). Good solutions on computers do not necessarily work equally well on tablets. These results further suggest that user experience investigated in one technological context cannot necessarily be transferred to another.

Our results support UX as a key concept for digital education products and indicate that UX models can be used to predict outcome variables similarly to technology acceptance models (Šumak et al., 2011). UX could advance the discussion on technology acceptance because it is rooted in concrete experiences and design solutions (Amadieu et al., 2019).

Our study provided some evidence that UX can explain variance in concept map scores, but the finding did not hold for all conditions. Given the growing importance of assessment with digital technologies (Redecker & Johannessen, 2013; Ng, 2015), research should systematically investigate the impact of UX on such assessment scores to ensure fair conditions for learners and create positive experiences of learning with technology.

11.4.3.1 Design recommendations

Several recommendations for the design of digital assessment and learning tools can be derived from our study as well. First, we recommend that designers consider the role and importance of individual psychological needs with regard to the product or service they are designing. Such a "product-specific needs profile" (Desmet & Fokkinga, 2020, p. 11) could potentially serve as a useful guideline for designing a positive user experience (which in turn impacts intention to use). Second, we found evidence that experience is strongly impacted by technology. The found differences between tablets and computers suggest that it is necessary to account for technology-specific adaptations like touchscreen-based interaction patterns to provide equally positive experiences. Such adaptations appear to be worthwhile because, third, we found strong support for viewing UX as a success factor for digital products. Fourth, our results indicate that UX might have an impact on outcomes, namely the scores achieved in concept map-based assessment. Although our results suggest a need for further research into why and when UX impacts assessment outcomes, the growing digitalization of education makes it necessary to consider products from a design-driven perspective to ensure that they provide appropriate circumstances for learning and assessment.

11.4.3.2 Limitations

The present study has three limitations. First, although most ω values were acceptable, the value for influence and popularity (ω = 0.61) was relatively low. However, this particular need was also rated as relatively unimportant for digital concept mapping and therefore only played a minor role in our setting.

Second, although the majority of learners were able to gain new knowledge, scores on the paper concept maps (pre-learning) and digital concept maps (post-learning) were relatively close to each other. Thus, the incentive to learn may have been low and might not generalize to situations in which the concept mapping scores affect students' grades (Heidig et al., 2015). However, studying the impact of user experience on concept map scores in a higher-stakes situation for participants would pose ethical challenges: Design issues with the concept mapping tool might systematically penalize certain groups of learners. Thus, we consider the relatively low overall learning success acceptable for the purpose of this study.

Third, UX is primarily related to perceived qualities (Hassenzahl, 2010). However, less subjective factors like the time needed to create a proposition might also play a role, particularly when it comes to assessment scores. Therefore, it might be worthwhile to replicate this study with additional objective measurements of the interaction such as a log system. This approach would allow researchers to triangulate participants' subjective evaluations with their objective behavior.

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12 “Each Shape has a Meaning”: Towards a Multimodal Grammar for Concept Maps

Abstract

Multimodal features like colors, shapes, typography, images, and audio are prominent in digital concept mapping tools. They have been suggested as viable means to enhance the method of concept mapping. However, there is little research on their meaningful use, particularly regarding active concept mapping and concept map-based assessment. The present paper presents the work-in-progress development of guidelines and a scoring rubric to help learners and instructors use multimodal features meaningfully in digital concept mapping. First, the paper presents results from a study on learners’ uses of multimodal features and identifies functions behind these uses. Second, the paper presents recommendations for developing materials intended to help learners and instructors use multimodal features in concept mapping, derived from three workshops with experts in human-computer interaction and education. The results are incorporated into a work-in-progress suggestion of guidelines and a scoring rubric for multimodal features in concept mapping, intended to inspire a scholarly discussion for their further enhancement. The next steps and implications are discussed.

12.1 Introduction

The use of multimodal elements like color, shape, or images in concept maps is characterized by a discrepancy. On the one hand, using multimodal features in concept maps is established: These features are readily available and frequently used in concept mapping tools like CmapTools (Cañas, 2005; Miller et al., 2008). Learners often requested multimodal features in a co-design study for an ideal concept mapping tool. They were associated with freedom and creativity to express content and a positive, pleasurable experience in concept mapping (Rohles et al., 2019). Several authors discussed their potential to enhance concept mapping (Alpert, 2005; Alpert & Grueneberg, 2000; Nesbit & Adesope, 2013). On the other hand, research about multimodal features in concept mapping is still relatively scarce (Chiou et al., 2012) and is mostly limited to studying concept maps as instructional materials. Multimodal elements are not often considered in scoring (see Chapter 10), and guidelines about their use in active concept mapping are missing.

The present paper investigates the use of multimodal features in digital concept mapping from the users’ perspective. It presents a work-in-progress development of guidelines and scoring rubrics to help in meaningful use and evaluation of multimodal features in digital concept mapping. Thus, the current paper contributes to addressing the discrepancy mentioned above.

12.2 State of the Art

12.2.1 Modes and Multimodality to Make Meaning

The term “mode” refers to meaning-making resources (Bezemer & Kress, 2008; Kress et al., 2001). Modes are, for example, verbal (e.g., written or spoken language) and non-verbal (e.g., photos, videos, and other visual elements; Moreno & Mayer, 2007). The term “modality” refers to sensory reception, for example with the ears (auditory) or eyes (visual; Weidenmann, 2002; Moreno & Mayer, 2007). “Multimodality”, finally, is the combination of several of these modes so that they influence each other (Bucher, 2007).

The terms “mode” and “medium” (and thus, “multimodality” and “multimedia”) are often used with close meanings, although “mode” generally refers to the generation of meaning, and “medium” refers to qualities like material and transmission (Kress et al., 2001; Lauer, 2009). For example, sound (as a medium) could transfer music or spoken language (as modes), and language (as a mode) could materialize in text or speech (as media; Kress et al., 2001. At the same time, characteristics of a medium influence which meanings can be communicated: For example, written language is not identical to spoken language (Lauer, 2009).

Multimodality investigates how meaning is created both intra-modally (within a single mode) and inter-modally (across different modes; Serafini, 2015; Unsworth, 2006). Intra-modally, each mode has particular capacities to create meaning (Bezemer & Kress, 2008; Kress et al., 2001; Kress & Leeuwen, 2021). Inter-modally, “meaning emerges from the interweaving between and across modes within a multimodal system” (Kress et al., 2001, p. 25). Theories on multimodality typically build on the three metafunctions of language suggested by Halliday (1978) to explain meaning-creation (Kress & Leeuwen, 2021; Unsworth, 2006):

- The *representational or ideational* function expresses something about the world. For example, an image of a person next to a text adds meaning to the message (e.g., what the person is wearing; Halliday, 1978; Kress & Leeuwen, 2021.
- The *interactive or interpersonal* function expresses something about the persons involved in communication. For example, a person in an image could be looking at the viewer or looking at something else. Thus, the gaze would either create a sense of interaction between the viewer and the represented person or shift the focus away from the viewer (Kress & Leeuwen, 2021).
- The *compositional or textual* function expresses something about the communication as a whole and how the different components relate to each other. For example, the image must be positioned at a particular place and in a particular size, and these decisions affect meaning (e.g., whether the image is illustrating the text or the text is illustrating the image; Kress & Leeuwen, 2021). Modes also have explicit means for specifying relations of components (e.g., arrows or pronouns pointing to other parts of a message; Kress & Leeuwen, 2021).

Two lines of research on multimodality are particularly important for the present paper. The first research line aims to identify how different modes create meaning. Typically, these approaches aim at establishing a “grammar” of modes by outlining how the metafunctions mentioned above are realized. Scholars have discussed the “grammars” of different modes, for example images (Kress & Leeuwen, 2021), color (Kress & van Leeuwen, 2002), or typography (Leeuwen, 2006; Serafini & Clausen, 2012; Stöckl, 2005).

The second research line aims to identify how meaning is understood in multimodal documents, usually building on the construct of coherence. *Coherence* denotes the relation between different parts of a document but “is not an attribute immanent to a text but the result of a communicative process of author and reader” (Schumacher, 2009, p. 69, translation by me; also see Gehl, 2013). Creating coherence is of vital importance to understand a multimodal document (Gehl, 2013; Schnotz, 2002). Stylistic means can help viewers understand the relations between modes (Gehl, 2013). These means can be positioned on a continuum from explicit (e.g., textual like “as the image on the right shows” or visual like arrows that point to an object) to implicit (e.g., based on Gestalt principles like positioning related elements close to each other; Gehl, 2013). Furthermore, research has investigated how viewers build coherence in multimodal documents. Such research contributed guidelines for the creation of multimodal documents, for example examining in which cases modes complement or compete with each other (Schumacher, 2009).

12.2.2 The Role of Multimodal Features in Learning

12.2.2.1 Learning Effectiveness of Multimodal Documents

Research on multimodal features in learning has focused on different angles. First, several studies investigated their effectiveness for learning. Several theories of memory suggest that human memory has different processing channels for different modalities, for example dual coding theory (Paivio, 1990), the multi-component model of working memory (Baddeley, 2000), theories of multimedia learning (Moreno & Mayer, 2007; Park et al., 2015), and cognitive load theory (Mousavi et al., 1995). Given that mental resources overall are limited (Moreno & Mayer, 2007), a meaningful combination of verbal and visual-spatial modes can enhance processing and learning of information, as compared to the use of either verbal or visual-spatial modes alone (Alpert & Grueneberg, 2000; Baddeley, 2000; Nesbit & Adesope, 2006; Mousavi et al., 1995; Paivio, 1990; Schnotz, 2002). A prerequisite for such enhanced learning is that these modalities are meaningfully integrated (Dwyer et al., 2013; Mousavi et al., 1995).

12.2.2.2 Aesthetics and Engagement with Multimodal Documents

Second, multimodal features can make concept maps look beautiful and aesthetically pleasing, thus increasing the engagement and motivation of learners. The terms “aesthetics” and “beauty” are often used interchangeably (Moshagen & Thielsch, 2010; Reber et al., 2004). Aesthetically pleasing design is inherently *positive* (humans perceive it as providing pleasure), *intrinsic* (humans perceive it without reflecting about its utility), and *objectified* (humans perceive it as a property of an object; Moshagen & Thielsch, 2010; Reber et al., 2004; Santayana, 1955). Thus, aesthetics can be defined as "an immediate pleasurable subjective experience that is directed toward an object and not mediated by intervening reasoning" (Moshagen & Thielsch, 2010, p. 690). Both properties of the object (for example, the choice of colors) and personal preferences by the observer play a role in creating this pleasurable experience (Moshagen & Thielsch, 2010).

What precisely makes a design aesthetically pleasing? Research has addressed this question from different angles. One angle was to identify specific characteristics of objects that are perceived as beautiful, for example novelty and typicality (Hekkert et al., 2003). Another angle, in particular taken by the Gestalt approach (Moshagen & Thielsch, 2010; Wagemans et al., 2012), emphasized that the whole of a form (a "Gestalt") is perceived before the individual components that make it up. Thus, Gestalt psychology concentrated on describing principles that govern the perception of whole figures, for example the principle of Prägnanz, the notion of the Good Gestalt, and various so-called Gestalt Laws to explain how humans mentally group visual elements (Padilla et al., 2017; Wagemans et al., 2012). Designs that follow these principles are easier to mentally process and thus perceived as aesthetically pleasing (Moshagen & Thielsch, 2010; Reber et al., 2004).

Aesthetics impact learning and motivation in multiple ways (Moshagen & Thielsch, 2010; Zain et al., 2007). For example, multimodal instructional material that follows design standards (like balancing elements or visually stimulating viewers) increases completion rates and lowers the time needed for completing the instruction (Szabo & Kanuka, 1998). The spatial arrangement of information was found to affect recall of information (Aspillaga, 1991).

12.2.3 Multimodal Concept Maps

Multimodal features in concept mapping include colors, shapes, different link styles, typography or the integration of photographs, videos, sound, tables, and other elements. Some authors have investigated multimodal concept maps, particularly as instructional materials. The main arguments were, first, that multimodal features increase the effectiveness of concept maps by allowing to represent a broader set of knowledge in a richer, more engaging way (Alpert, 2005; Alpert & Grueneberg, 2000; Keller & Tergan, 2005). Second, multimodal features could address the so-called "map shock" (Blankenship & Dansereau, 2000, p. 295) of learners: While research suggests that studying concept maps is, in principle, very effective (Nesbit & Adesope, 2013; Nesbit & Adesope, 2006), it can also feel overwhelming because there are no conventions how to read a concept map (Nesbit & Adesope, 2013). Multimodal features could support learners by making the reading order and importance explicit (Nesbit & Adesope, 2013).

Despite these advantages, research on the use of multimodal features in concept mapping is scarce when compared to research on other advantages of concept mapping (Chiou et al., 2012). Instructional concept maps with colors and images enhanced learning (Chiou et al., 2012; Tien et al., 2018), in particular for learners with disabilities or lower verbal skills (Anderson-Inman et al., 1998). Multimodal concept maps with animations improved learning and learner satisfaction (Blankenship & Dansereau, 2000; Chiou et al., 2015; Nesbit & Adesope, 2013). Multimodal concept maps with multimedia content affected learners' engagement by increasing the time spent creating concept maps (Sanchiz et al., 2019). Several studies demonstrated that a clear structure was beneficial for learning, mitigating the map shock mentioned above (Amadieu et al., 2009; Blankenship & Dansereau, 2000). Examples include concept maps where related elements have similar colors and shapes or are grouped spatially (following Gestalt laws; O'Donnell et al., 2002; Wallace et al., 1998).

The present paper contributes to the research on multimodal concept mapping from two angles. First, it investigates active concept map construction by learners, not concept maps as instructional materials (Nesbit & Adesope, 2013). Such active concept mapping with multimodal features is rarely researched. Other studies often had instructors or researchers pre-define the semantic meaning of multimodal features (Basque & Pudelko, 2004; Muis et al., 2016; Rocha et al., 2004). However, very few studies explored the creation processes of multimodal concept maps, particularly not including feedback from participants (Padilla et al., 2017). The study by Padilla et al. (2017) is a rare exception but concentrated on how participants structured content in concept maps (especially building on Gestalt laws), not on the role of multimodal features. The first contribution of the present paper is, thus, to investigate the functions of learners' uses of multimodal features in concept maps.

Second, the present paper investigates the value of multimodal concept maps in assessment. Only a small number of studies include multimodal features in scoring (see Chapter 10 and Strautmane, 2012). A limited number of studies included singular multimodal features like color (Calafate et al., 2009; D'Antoni et al., 2009; Muis et al., 2016), photographs (Byrne, 2011; D'Antoni et al., 2009), or web resources (Schacter et al., 1997). However, when learners are given high freedom in expressing content in multimodal concept maps (Preston, 2007), assessment needs a flexible procedure to account for this freedom. Earlier studies have suggested procedures like using multimodal concept maps to inspire a discussion with learners (Preston, 2007) or applying a qualitative analysis, for example based on phenomenographic (Mavers et al., 2002) or multimodal theories (Mavers, 2007; Preston, 2009). The present paper contributes a flexible scoring rubric that allows systematizing the assessment of multimodal concept maps, together with guidelines that help learners in meaningfully using these multimodal features.

12.3 Research Questions

The present paper addresses two research questions (see Fig. 65):

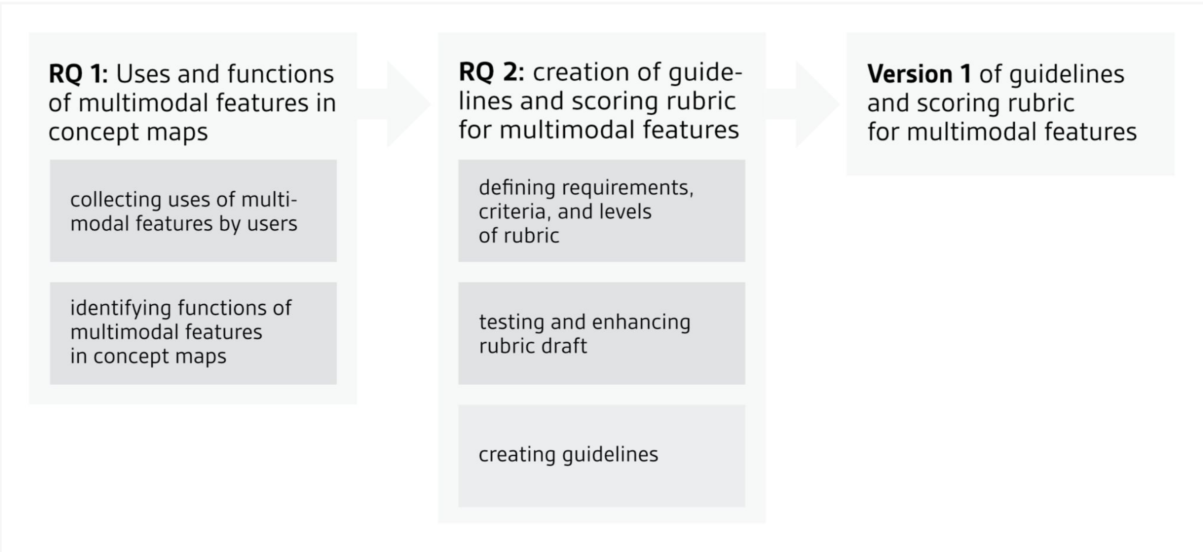
- *Research question 1 (RQ 1): What are the functions of multimodal features that make learners use them in their concept maps?*

RQ 1 investigates how learners use multimodal features in concept maps and the reasons for these uses. These insights will guide the creation of guidelines and a scoring rubric to help them achieve meaningful use of multimodal features.

- *Research question 2 (RQ 2): What should guidelines and scoring rubrics look like to help learners and instructors in achieving meaningful use of multimodal features in concept mapping?*

  RQ 2 contributes to creating flexible guidelines and a scoring rubric for multimodal features in concept maps by defining success criteria and examining the content and construct validity of early drafts of these materials.

***Fig. 65**: Research questions of the present paper*



12.4 Methodology

12.4.1 RQ 1: Uses and Functions of Multimodal Features for Learners

To identify what learners want to achieve with multimodal features in digital concept maps, I performed a lab-based experiment with 31 participants. Participants tested a digital concept mapping prototype while creating a concept map on their idea of digital learning. They were encouraged to use multimodal features. The prototype provided essential multimodal features like different colors of shapes and links, types of shapes, line types, and basic typography options[30]. There were no concepts or linking words or

[30] The prototype corresponded to prototype b-1 (see Chapter 8 for a detailed description).

other material provided to the participants. I deliberately chose this open and low-directed concept mapping approach to avoid restricting their use of multimodal features (Mavers, 2007).

After the tests, the participants presented their concept maps and explained their use of multimodal features. Similar to the procedure suggested by Mavers (2007), non-leading questions were used to inspire a discussion. The interviews were audio-recorded.

During the analysis, I created a summarizing protocol of the interviews (Mayring, 2002). Such a protocol aims at reducing the amount of information by assigning codes to key statements. For example, the statement “I want to create many kinds of shapes, like circle, oval, cloud, these kinds of tools” (P20) is a key statement for the code “more shapes needed”. Key statements for the identified codes were fully transcribed. The summarizing protocol was imported into MaxQDA and coded with the identified codes. Afterward, I went through the audio recordings and verified whether the codes adequately capture the statements’ meaning. Finally, codes were categorized into the themes reported in the results section.

12.4.2 RQ 2: Guidelines and Scoring Rubric for Multimodal Features

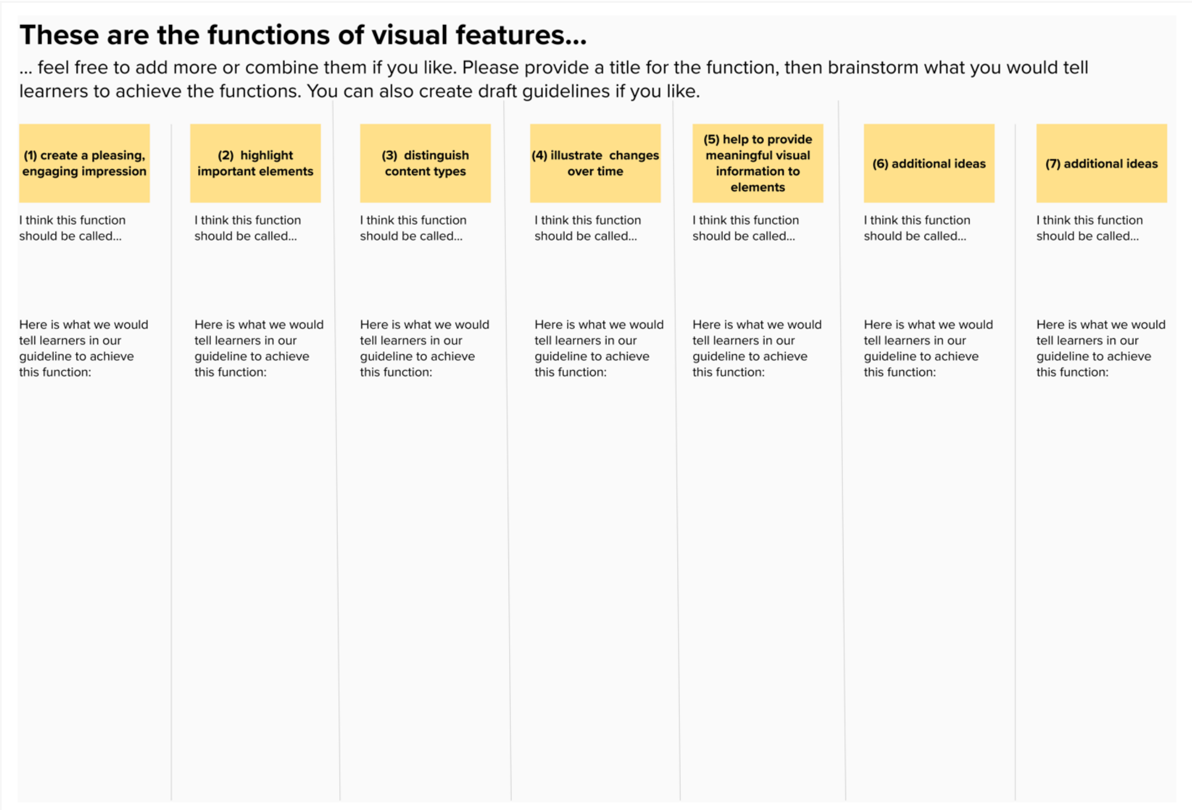
As a preliminary step, I investigated different approaches to scoring multimodal features and finally opted to develop a scoring rubric. A rubric is a “*coherent set of criteria for students' work that includes descriptions of levels of performance quality on the criteria*” (Brookhart, 2013, p. 4, italics in the original). Rubrics can be holistic or analytic: Holistic rubrics judge all criteria jointly to create one overall evaluation. Analytic rubrics describe criteria of performance evaluated separately and allow learners to see which areas of their work need attention (Brookhart, 2013). Rubrics have several advantages that make them an appropriate choice for the present paper. They allow to assess authentic learner work, provide detailed feedback, allow for self-review or peer review and act as guidelines that inform learners about what is considered appropriate in performance (van Helvoort et al., 2017). Rubrics are also established as scoring methods in concept mapping (see Chapter 10). Thus, I decided to create an analytic scoring rubric for multimodal features in concept maps.

Rubrics have two main components: criteria and levels (Brookhart, 2013). Criteria describe the learning outcomes, and levels describe differences in the performance (Brookhart, 2013). The quality of a rubric is typically assessed in terms of reliability and validity (Moskal & Leydens, 2000). Reliability means that a high-quality rubric should yield consistent assessment results and is typically verified as interrater agreement (Moskal & Leydens, 2000). Validity means that a rubric should be appropriate for what it is supposed to measure (Moskal & Leydens, 2000). Validity is achieved with different approaches. *Content validity* investigates whether the learner responses reflect their knowledge in the area of interest (Moskal & Leydens, 2000). *Construct validity* investigates whether all criteria in the rubric are relevant for the construct (Moskal & Leydens, 2000; van Helvoort et al., 2017). *Criterion validity* investigates whether the scores from the rubric correspond to scores from other measurement tools (van Helvoort et al., 2017).

The present paper presents a work-in-progress development of a rubric and guidelines for multimodal features in concept mapping. It provides first evidence for content validity and construct validity by reviewing drafts of the rubric with a team of experts and discussing whether all relevant aspects of the content area are covered (van Helvoort et al., 2017). In particular, the scoring rubric and guidelines were developed in an iterative process in three remote workshops with a group of experts in human-computer interaction (HCI) and education. All participants worked full-time in HCI and had at least three years of experience in the field, and four of the participants worked full-time in projects that investigated educational uses of technology. Their educational levels included post-doctoral (3 participants), doctoral (5 participants), and master education (3 participants). All experts received a detailed introduction to concept mapping. In the following, I will outline the procedures. A detailed description of the drafts is included in the results section. The iterative process to create the scoring rubric and guidelines followed a three-step approach:

- The first workshop focused on collecting requirements for the materials. The experts first engaged in an ice-breaker discussion about advantages and challenges of using multimodal features in concept maps. Afterwards, I presented an early draft of a scoring rubric based on the functions of multimodal features in concept maps identified in RQ 1. The experts applied the scoring rubric to two learner-generated concept maps from a previous study on sustainability (see Chapter 11) and provided feedback. Feedback concentrated on how essential the functions and features are and an open question for enhancements of the scoring rubric. I incorporated their feedback into a revised draft of the scoring rubric.
- The second workshop focused on applying, evaluating, and enhancing the revised scoring rubric. First, each expert practiced the scoring rubric with at least two concept maps from a set of six learner-generated concept maps from a previous study on sustainability (see Chapter 11). The evaluations were collected with an online survey tool. Second, each expert evaluated the content validity of the scoring rubric using a questionnaire derived from recommendations by Brookhart (2013). The questionnaire asked to (a) evaluate the criteria for relevance, clarity, and easiness to observe (using a 5-point scale), (b) provide feedback regarding completeness and distinctness of the criteria (using open questions), and (c) evaluate the descriptions for each proposed level. Third, the experts discussed the rubric and provided suggestions for enhancements.
- The third workshop focused on converting the rubric into guidelines. The experts collected and discussed requirements for such guidelines. These discussions served as inspiration for the following brainstorming. During the brainstorming, the participants split into two groups and created ideas for each function of multimodal features using a provided template (Fig. 66). Finally, each group shared and discussed their ideas.

Fig. 66: *Template used in the third workshop*



The answers from the three workshops were imported into MaxQDA. A qualitative summarizing content analysis (Mayring, 2002) was performed to identify and assign codes to statements by the participants. After coding the qualitative statements, I went through the answers again and verified whether the codes adequately cover the content. This quality check was repeated after several months when working on the present paper. Finally, the related codes were grouped into the results presented in the following sections. Direct quotes are included in italics where appropriate.

12.5 Results and Discussion

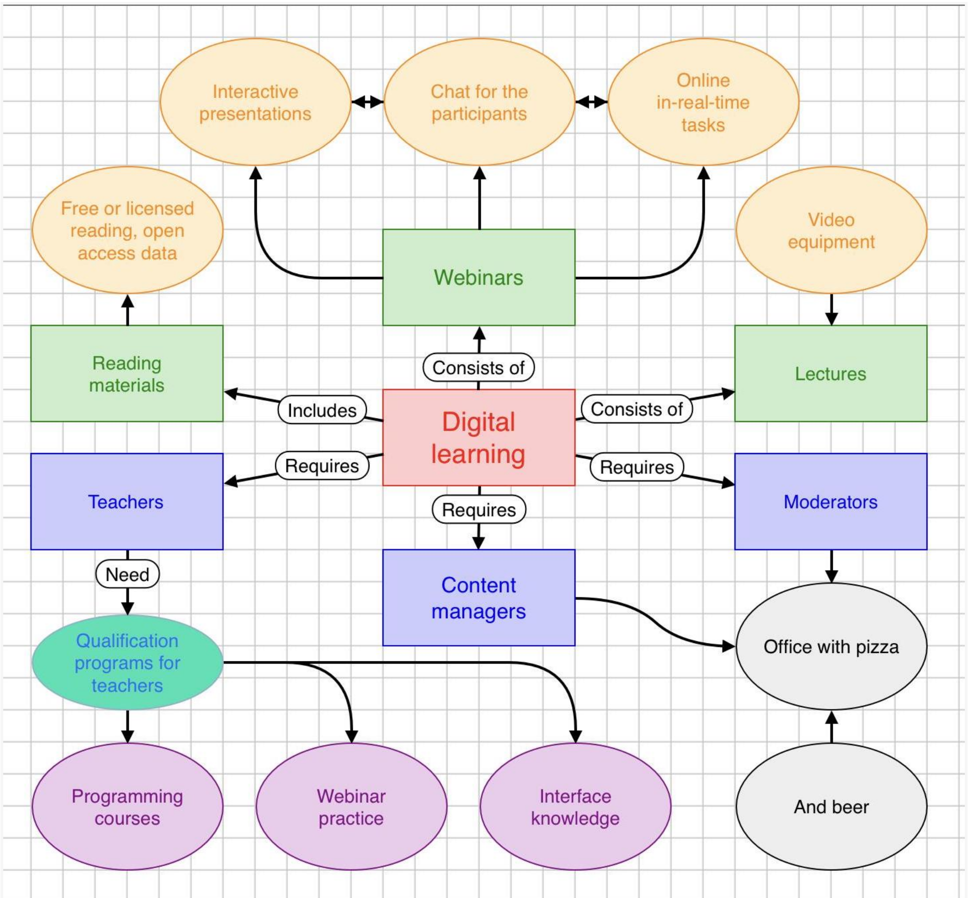
12.5.1 RQ 1: Uses and Functions of Multimodal Features

Prior studies in the present research project have revealed a high need for multimodal features in concept mapping (see Chapter 2). Participants' uses of multimodal features support this importance. I have identified three functions behind these uses: content-driven (15 participants), attention-driven (7 participants), and decorative or expressive uses (5 participants). Three participants did not use any multimodal feature.

12.5.1.1 Content-driven Uses of Multimodal Features

First, content-driven uses express content aspects with multimodal features to enhance understanding (P27: "I like very much that you can change the colors. I really liked that stuff. I think that colors make everything easier to understand.”). Participants frequently distinguished categories of concepts, for example by color (seven participants, see Fig. 67) or shapes, indicating a multimodal grammar for concept maps would be needed (P26: “each shape has a meaning, something like that would be good”). Besides categories, three participants emphasized the central concept because it defined the overall topic of the concept map (P3: “the purple is different, it is the only one, it shows that it is the subject and it is in the middle”). These content-driven uses mostly belong to the ideational meta-function (Halliday, 1978; Kress & Leeuwen, 2021). However, some uses were interpersonal (Halliday, 1978; Kress & Leeuwen, 2021), in particular subjective evaluations of concepts (positive and negative factors, three participants). Sometimes, learners used multimodal features (along with layout and hierarchy) to emphasize the composition of the concept map (Halliday, 1978; Kress & Leeuwen, 2021) by distinguishing levels and branches of concept maps (P30, P31).

Fig. 67*: Example of the content-driven use of multimodal features to distinguish different categories of content (P7)*



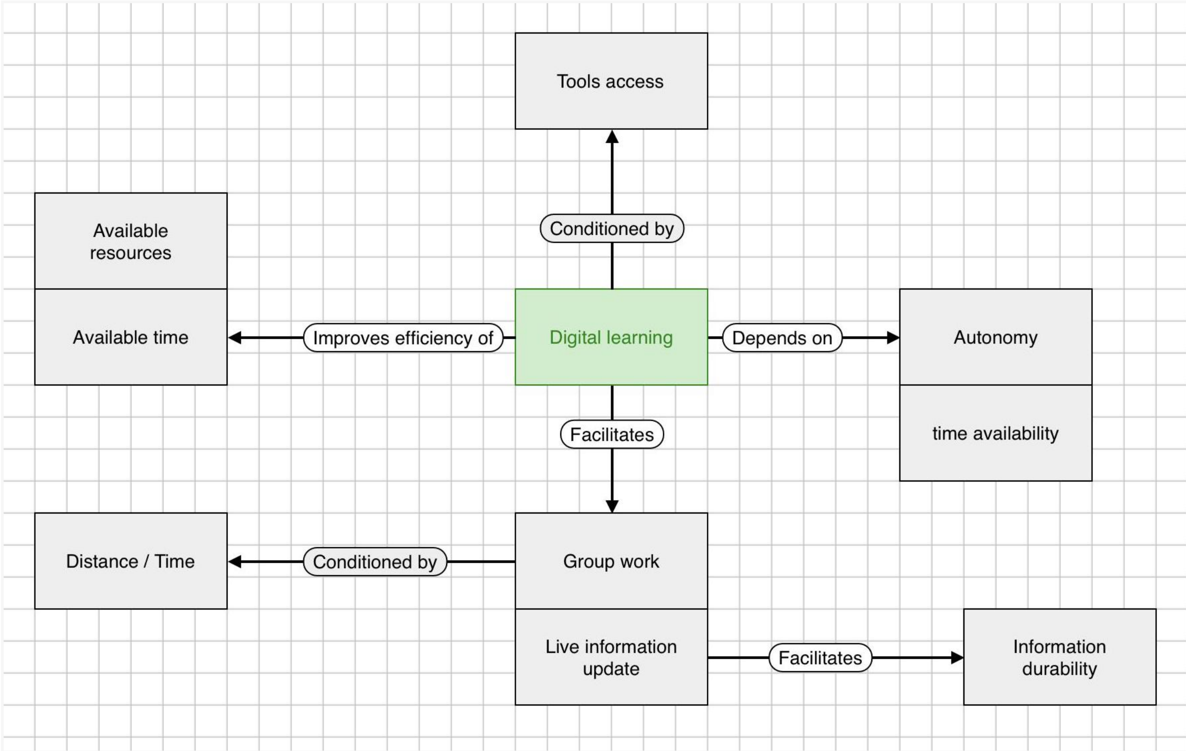
Line types were sometimes used similar to auxiliary verbs like “might” or “could” in language. For example, P2 explained the use of a dashed line instead of a solid line as follows: “What I wanted to do with these is that an excessive use could cause disadvantages. It is not really a link, you could use it so much and not have disadvantages. Like I could use my TV everyday and still be a good student and learn.” Such validity statements belong to the interpersonal meta-function because learners position themselves in terms of how credible a connection is in their view (Halliday, 1978; Kress & Leeuwen, 2021).

Finally, discussions with participants revealed that content-driven uses of multimodal features need to be explicit to facilitate understanding. Several participants did not include such explicit markers because "these are my thoughts, my brain, that is I know very well why I have made this arrow, therefore I left it like that later because I forgot and also did not need it" (P22). However, without the verbal explanation, the semantic meaning of the represented links is difficult to define. P24 suggested a "default connection" with a specific, general-purpose meaning for links without labels: "[…] these were more of keywords for me where the connection would have been 'is a part of', therefore it was not that important for me".

12.5.1.2 Attention-driven Uses of Multimodal Features

Second, attention-driven uses specify which elements are the most important (ideational) and attract viewers' attention (interpersonal; Halliday, 1978; Kress & Leeuwen, 2021). Similar to earlier research, participants used multimodal features to emphasize core ideas (Padilla et al., 2017). Often, attention-driven uses were combined with content-driven uses. Examples include when learners emphasized the central concept for its topic-defining role of a concept map or when particular categories are viewed as more important than others: "I used more colors here to make it stick out and be in the foreground. I also used colors for the categories to make them stick out so that you see: there is a main topic with two categories that are different. I made listings and examples grey because they are less important and should not stick out" (P22). Attention-driven uses were also often combined with decorative or engaging uses, for example by P24, who suggested effects and animations, particularly to make a concept map more attractive for children.

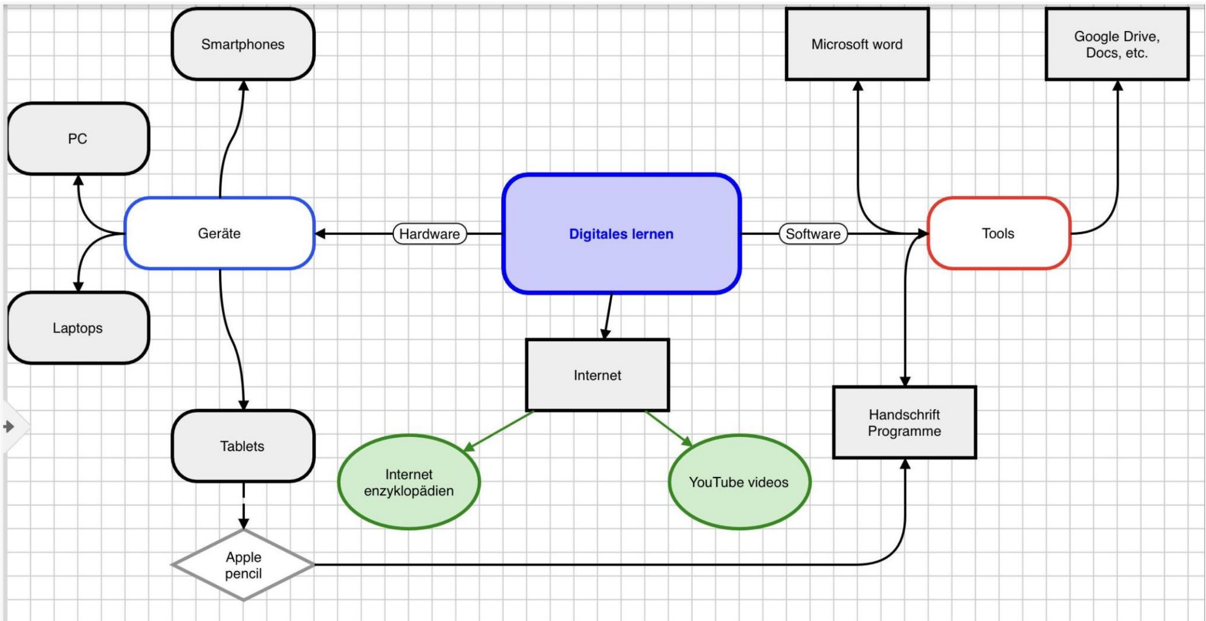
Fig. 68*: Example of the attention-driven use of color to emphasize the core topic and space to create groups of related elements (P27)*



12.5.1.3 Decorative or Engaging Uses of Multimodal Features

Third, decorative or engaging uses attempt to achieve aesthetically pleasing concept maps. Multimodal features can help in making concept maps beautiful (P9) and give them an emotional meaning (P22, P23): "I wanted to use the functionality with the colors so that I can empathize better with the map. […] I used green for the arrows because green is my favorite color" (P22). Likewise, P10 emphasized that creativity is at the core of using multimodal features and felt the prototype to be missing relevant options ("I like creativity, to have options to decide. And this might be a little bit limiting. I like to express myself.")

Fig. 69: *Example of the decorative or engaging use of color (P22)*



12.5.2 RQ 2: Guidelines and Scoring Rubric for Using Multimodal Features in Concept Mapping

12.5.2.1 Workshop 1: Defining Criteria and Levels of a Scoring Rubric

The first workshop aimed at identifying criteria and levels of the analytic scoring rubric (Brookhart, 2013; McDonald, 2015). In particular, it covered modes and functions. Regarding the modes, the draft suggested the following multimodal features: color, shape, size, use of icons, use of images, typography, layering of information (for example by nesting concept maps into main and sub concept maps), spatial arrangement, and temporal dynamics (for example by adding animations that demonstrate the flow of a process described in a concept map). The functions were derived from RQ 1 as follows:

- **decorative and engaging**: Multimodal features are used for decoration or engagement to make the concept map look motivating to read.
- **attention-driven**: Multimodal features are used to guide attention, for example by stressing important elements.
- **content-driven**: Multimodal features are used for communicating meaning, for example by distinguishing different categories of elements.
- **explicit**: Multimodal features are explained explicitly (e.g., with a legend).

I arranged the modes and functions in a framework (see Appendix K). The experts applied the framework of modes and features to two concept maps as a basis for their feedback. The feedback concentrated on discussing the modes and features as criteria and levels of a to-be-developed scoring rubric.

In their feedback, participants often mentioned that the different modes might overlap to reach a particular purpose. For example, learners could use color, typography, shape, or other modes to categorize concepts. The experts emphasized that the overall goals of meaningful use of multimodal features are coherence and clarity, such as avoiding that features contradict each other (e.g., when both color and shape are used for categorization). Several findings referred to discussing which mode is the most appropriate for a particular purpose. For example, the experts emphasized that a strength of typography is that "it can communicate content in a very unobtrusive way" (P8) and that "it helps emphasize certain content types in a more subtle way than color or shape" (P2). All of these findings indicate that the functions are the driving factors of meaningful use of multimodal features in concept mapping, not the mode (P2: "I would base the scoring on the visual functions because they can be realized via different features. You never need all of the features but you need all of the functions"). Consequently, I decided to implement the identified functions as criteria of the scoring rubric.

12.5.2.2 Workshop 2: Enhancing a Scoring Rubric for Multimodal Features

I synthesized the feedback from workshop 1 into a scoring rubric draft. The draft included the identified functions as criteria and textual descriptions of performance as levels (see Appendix L). Each expert applied the scoring rubric draft to at least two concept maps and provided feedback about the criteria and the levels of the scoring rubric draft.

Enhancing the criteria of the scoring rubric draft

The scoring rubric draft identified the following functions as criteria:

- **Aesthetics**: use design to create a nice, pleasing look that helps to engage with the concept map. The function "aesthetics" corresponds to the function "decorative or engaging" from the workshop 1.
- **Attention**: use design to guide the focus, e.g., to the most important aspects.
- **Content**: use design to distinguish content, e.g., by categorizing it.
- **Dynamics**: use design to highlight relevant changes in the described content, e.g., by highlighting feedback loops. The function of "dynamics" was suggested as an enhancement to concept mapping (Safayeni et al., 2005) and is particularly relevant for dynamic topics.
- **Illustration**: use design to provide meaningful additions to the concept map, e.g., by adding images, videos, or other resources to concepts. The function of "illustration" was suggested by several participants in the study in Chapter 8 but was not available in the tested prototype. Several participants mentioned that adding images, videos, or audio files to the concept map would be appropriate.

I analyzed experts' evaluations and qualitative feedback for these functions. Table 23 presents how the experts assessed the quality of the scoring rubric using a 5-point scale, following suggestions by Brookhart (2013). The evaluated quality characteristics were appropriateness ("How appropriate/relevant are the criteria for evaluating the use of multimodal features in concept maps?"), clarity ("How clear are the criteria for evaluating the use of multimodal features in concept maps?"), and easiness ("How easy to observe are the criteria for evaluating the use of multimodal features in concept maps?").

***Table 23**: Evaluation of quality criteria for characteristics of scoring rubrics (Brookhart, 2013) on a 5-point scale*

characteristic	aesthetics	attention	content	dynamics	illustration
appropriateness	$M = 5$ $SD = 0$	$M = 4.4$ $SD = 0.89$	$M = 4.8$ $SD = 0.45$	$M = 3.2$ $SD = 0.45$	$M = 3.6$ $SD = 1.67$
clarity	$M = 4.4$ $SD = 0.55$	$M = 3.8$ $SD = 0.84$	$M = 4.4$ $SD = 0.55$	$M = 2.6$ $SD = 1.34$	$M = 3.8$ $SD = 0.45$
easiness	$M = 4.8$ $SD = 0.45$	$M = 4$ $SD = 1.22$	$M = 4.2$ $SD = 0.45$	$M = 2$ $SD = 0.71$	$M = 4.8$ $SD = 0.44$

The functions of aesthetics and content score very high on these criteria. Qualitative feedback revealed that some experts associated the descriptions of aesthetics with readability (e.g., "The design is pleasing and makes the concept map a pleasure to read.", indicating that a term like "look at" would be preferable) and evaluated the term "content" as too general. Attention scores high but overall shows a slightly larger standard deviation. Qualitative feedback revealed that experts found attention to partially overlap with other criteria like aesthetics or dynamics. Reasons were mainly because these were associated with creating attention, for example by strongly associating aesthetics with color and dynamics with animation. Dynamics was the most challenging function. The experts evaluated the descriptions as less clear and easy to apply, indicating a need to rephrase the descriptions. Finally, illustration was rated high in easiness and clarity. Appropriateness ratings of illustrations were high except for one expert who emphasized that concept maps should not include images.

In conclusion, the experts evaluated the criteria and their descriptions as relevant, but naming and distinction issues remained. As a consequence, I converted the descriptions into short phrases (e.g., "meaningfully distinguish types of content" instead of "content") and asked the experts to suggest names for these functions in the third workshop. As suggestions for further functions, some experts proposed a dimension relating to the layout and structure of a concept map, similar to other scoring rubrics (Besterfield-Sacre et al., 2004).

Enhancing the levels of the scoring rubric draft

Besides the functions, my scoring rubric draft specified levels to describe the quality of multimodal feature use (Brookhart, 2013), for example "The design does not include any element that meaningfully adds relevant criteria to the content.“ (for the lowest performance level). I assessed their quality based on criteria suggested by Brookhart (2013) for each function. Table 24[31] contains the experts' evaluations of the quality of the levels.

***Table 24**: Evaluation of quality criteria for levels of scoring rubrics (Brookhart, 2013) on a 5-point scale*

Question	Aesthetics	Attention	Content	Dynamics	Illustration
adequate	$M = 4$ $SD = 0.71$	$M = 3.6$ $SD = 0.55$	$M = 4.4$ $SD = 0.55$	$M = 2.8$ $SD = 1.1$	$M = 4.4$ $SD = 0.55$
clear and understand-able	$M = 4.2$ $SD = 0.45$	$M = 3.8$ $SD = 0.84$	$M = 4$ $SD = 0.71$	$M = 3.4$ $SD = 0.55$	$M = 4.4$ $SD = 0.55$
whole spectrum	$M = 4.4$ $SD = 0.55$	$M = 4.4$ $SD = 0.89$	$M = 4.4$ $SD = 0.89$	$M = 4$ $SD = 1$	$M = 4.6$ $SD = 0.55$
distinguish levels	$M = 3.8$ $SD = 0.84$	$M = 3.4$ $SD = 1.14$	$M = 3.4$ $SD = 0.89$	$M = 3.6$ $SD = 1.14$	$M = 3.6$ $SD = 0.55$
match levels of performance	$M = 3.75$ $SD = 0.5$	$M = 4.25$ $SD = 0.5$	$M = 4.5$ $SD = 0.58$	$M = 4$ $SD = 0.82$	$M = 3.75$ $SD = 1.26$
move from level to level	$M = 3.6$ $SD = 1.14$	$M = 4.2$ $SD = 0.45$	$M = 3.8$ $SD = 0.84$	$M = 3.8$ $SD = 0.84$	$M = 4$ $SD = 1$

Overall, the experts evaluated the levels as adequate, clear, and understandable. The criteria of attention and especially dynamics score lower on the criterion of adequateness, mirroring the issues with the descriptions outlined above. Further qualitative feedback revealed that the experts evaluated the six levels as too many and suggested using three or four levels (plus a "not required" or "does not apply" level). A minority of participants understood the level descriptions as an invitation to count multimodal features. Consequently, the descriptions of the levels should be adapted to emphasize that they are evaluating the overall appearance (Brookhart, 2013). Finally, some experts felt uncomfortable because "does not apply" was the lowest level. Instead, they suggested that the scoring rubric should not present a dimension if it does not apply to a topic. Thus, I converted the rubric into a modular rubric where instructors could only include relevant functions for the target topic.

Furthermore, I performed an exploratory check of agreement. Each expert applied the scoring rubric draft to at least two concept maps. The agreement was promising. Around half of the ratings of the six concept maps were either fully aligned or aligned within one level. While these ratings are a preliminary exploration only, they are encouraging that a high agreement can be reached when the remaining issues

[31] The items were: The descriptions adequately describe what to look for when evaluating a concept map on the criterion. The descriptions are clear and understandable. The descriptions cover the whole spectrum of the criterion. The descriptions adequately distinguish the different levels of the criterion. The descriptions adequately match the level of performance they are assigned to. The descriptions adequately move from level to level.

of the scoring rubric are addressed. Afterward, a systematic study of the reliability of the scoring rubric is needed.

12.5.2.3 Workshop 3: Creating Guidelines for Multimodal Features in Concept Mapping

Following workshop 2, the functions of multimodal features were converted into descriptions. I asked the participants to suggest general terms to denominate each function:

- **(1) help create a pleasing, engaging impression**: General terms for this function were very diverse and included generic suggestions like “overall impression” or “graphic design”, repetitions of previously discussed terms like “aesthetics”, and playful ideas like “pimp your map!”. Some experts distinguished between “pleasing” and “engaging” functions. Thus, the naming and definition of this function of multimodal features remain areas of further research.
- **(2) help to meaningfully distinguish important elements**: Terms like “emphasize”, “visual hierarchy”, or “highlight” were suggested as general terms. The notion of emphasis was the most frequent and appeared to be a suitable candidate.
- **(3) help to meaningfully distinguish types of content**: Experts mainly referred to the term “categorization” or close variations as a general term to denote the function.
- **(4) help to explain how the topic changes or evolves over time**: General terms suggested for this description included “evolution”, “sequence”, “process”, “timeline”, and “flow”. They all cover the dynamic nature of these multimodal features but have different focus points that might not relate to every topic. For example, “evolution” might be an appropriate term for concept maps that describe how something develops (e.g., how a seed evolves into a tree) but not for concept maps that describe how something functions (e.g., how a fuel cell works). Thus, combining these terms might better cover the full spectrum of dynamic content in concept maps.
- **(5) help to provide meaningful visual information to elements**: General terms suggested for this description were “visual media”, “enrich”, and “detail”. The adjective “visual” should be complemented with other adjectives (e.g., “visual, textual, or auditory media”) because not all additional information is of visual nature (e.g., audio recordings).

Afterward, the experts provided suggestions for guidelines, intended to help learners achieve the functions. Suggestions fall into four categories:

- **Making the use of multimodal features explicit**: Several suggestions specified that the guidelines should include the need to make the semantic meaning of multimodal features explicit as a general requirement, for example using a legend. Functionalities to provide these legends have been reported for some concept mapping tools, e.g., Webster (Alpert & Grueneberg, 2000).

- **Providing useful brief guidelines and suggestions**: Several suggestions included general design guidelines, for example "Things that belong together should look similar", "Consider size, color, and other stylings that draw the eyes", or "make important elements appear bigger".
- **Outline an appropriate process**: Several suggestions attempted to structure the process of applying multimodal features to concept maps, for example, "first create the content of the map, then take a few minutes to pimp it" or "start by defining the types of content that are included in the concept map". These suggestions could be converted into step-by-step guidelines that help learners get the most out of their time for creating a concept map.
- **Critical questions to assess the usefulness of multimodal features**: Several suggestions included questions to ask before using a particular multimodal feature, for example, "Where do you best put your elements on the concept map?". These questions serve as necessary checks of the usefulness of a multimodal feature.

12.6 Conclusion

The present paper explored the use of multimodal features in concept mapping from the perspective of users. First, RQ 1 investigated patterns of use for multimodal features. Learners particularly used multimodal features to a) categorize elements into meaningful groups (content-driven uses), b) emphasize important elements to capture attention (attention-driven uses), and c) make concept maps aesthetically pleasing to create engagement (decorative or engaging uses). The study also revealed the need to enrich concept maps with additional information (such as by adding images, videos, or audio files) or making the use of multimodal features explicit (for example, by adding a legend or defining a multimodal grammar for concept maps). Furthermore, three workshops with experts in human-computer interaction and education were performed to create guidelines and a scoring rubric for multimodal features in digital concept maps (RQ 2).

12.6.1 Towards Guidelines and a Scoring Rubric for Multimodal Features in Concept Maps

12.6.1.1 Identification of Functions for Multimodal Features in Concept Maps

Appendix M contains the final draft for guidelines and scoring rubric. It currently has three sections. Section 1 describes the functions of multimodal features. Each function has a label and a short, actionable description:

- **Beauty and aesthetics**: create a pleasing impression
- **Emphasis and salience**: meaningfully distinguish important elements
- **Categorization**: meaningfully distinguish types of content
- **Evolution, sequence, or process**: explain how a topic changes or evolves over time

- **Enriching or adding elements**: provide meaningful visual, textual, or auditory elements
- **Validity**: communicate how valid the content elements are
- **Layout and composition**: arrange elements in a meaningful way

The labels correspond to the suggestions from workshop 3. The most difficult label is "beauty and aesthetics". The term "aesthetics" was interpreted as a general term for multimodal features by some participants in workshop 2, but was re-introduced by participants in workshop 3. The definition of aesthetics as "an immediate pleasurable subjective experience that is directed toward an object and not mediated by intervening reasoning" (Moshagen & Thielsch, 2010, p. 690) fits well with the function of creating a pleasing impression. Thus, the term "beauty" was added given its closeness to aesthetics (Moshagen & Thielsch, 2010; Reber et al., 2004) to avoid the misinterpretation as a general-purpose term.

Two functions were added after workshop 3. Validity was not identified as a function by the experts but was included by learners (RQ 1). Furthermore, it is discussed in multimodal theory. In language, auxiliary verbs like "might", "may", or "will" serve interpersonal functions (Kress & Leeuwen, 2021): When saying that "the results might indicate something" instead of "the results indicate something", speakers position themselves regarding how much validity they ascribe the results by expressing some caution. Such interpersonal functions could be introduced into concept maps by adopting an appropriate multimodal grammar, for example, a dotted or dashed line instead of a solid line, or by using a slight trembling animation to make a line appear less stable (Padilla et al., 2017). The function of layout and composition corresponds to a frequent suggestion by the experts in workshop 2.

Appendix M also has a description for each function and additional checks to help learners achieve the respective function. Care was taken to make the descriptions and suggestions general and non-leading, without suggesting a concrete design feature (for example, using color for categorization).

12.6.1.2 Description of General Principles

Section 2 identifies general principles that apply across all functions and features. Based on discussions with participants (RQ 1) and experts (RQ 2), four general principles were included:

1. The **principle of explicitness and coherence** suggests making the use of multimodal features easy to understand, for example, by following conventions or creating a legend.
2. The **principle of structured concept mapping** suggests a process for multimodal features. It advises focusing on the content first and working on multimodal features close to finishing the concept map, avoiding that learners lose too much time at the beginning of the map creation by playing around with multimodal features before they have a concrete idea of what these features should achieve.
3. The **principle of meaningfulness of multimodal features** suggests using multimodal features only when they serve the identified functions.

4. The **principle of accessibility** follows experts' suggestions to avoid creating barriers of understanding (for example, do not solely rely on colors when viewers have color deficiencies) and create an additional layer to understanding a concept map (for example, support viewers with weaker language skills with a clear and coherent structural representation).

12.6.1.3 Multimodal Scoring Rubric

Section 3 presents a scoring rubric. Following suggestions from workshop 2, it is created in a modular fashion: Instructors and researchers can choose which functions apply to a particular concept mapping task. For example, they could decide whether learners should be concerned with making their concept maps aesthetic and beautiful, and if yes, they would apply the "beauty and aesthetics" module as a criterion for scoring. Thus, the modular structure of the rubric allows instructors and researchers to clearly define which functions of multimodal features are appropriate for a given concept mapping task. Learners could then use the selected criteria to guide their concept mapping towards the intended outcomes.

Besides the modular criteria, the scoring rubric contains levels as descriptions of performance (Brookhart, 2013). The amount of levels has been reduced to four. The descriptions closely resemble the suggestions from workshop 2 but have a clear separation between the levels:

- level 0: no efforts to implement a function, not achieving a function
- level 1: limited effort to implement a function, generally not achieving a function but providing some indications of attempting it
- level 2: considerable effort to implement a function, generally achieving a function but with room for improvement
- level 3: fully achieving a function

The level descriptions are written in a general, non-leading fashion that avoids giving concrete suggestions (e.g., verifying how many colors are used).

12.6.2 Implications and Contributions

The present paper has three main implications and contributions. First, it contributes to helping learners reflect on their concept maps. In a study on psychological needs in concept mapping, learners, instructors, and researchers emphasized that concept mapping is a competence of its own that learners need to acquire (see Chapter 4). However, approaches to help learners build this concept mapping competence are rarely investigated in research (Roessger et al., 2018). The guidelines presented in this paper could be used for providing feedback for the use of multimodal features in concept mapping. Beyond enhancing the content that is expressed with concept maps, multimodal concept mapping can also contribute to developing visual literacy (Szabo & Kanuka, 1998) or multiliteracy (Serafini, 2015).

With the growing digitalization of education, in particular instruction and assessment tasks involving multimedia elements, the need for these literacies is rising (Szabo & Kanuka, 1998).

Second, the present paper contributes to the scoring of multimodal features in concept maps. Scoring rarely considers multimodal features (see Chapter 10). However, this situation is challenging because scores would be different for a learner who uses multimodal features to denote meaningful content details (like categories) and a learner who uses propositions to denote these details. I am not implying that scoring should always consider multimodal features: there are situations where these features are out of scope. However, in these situations, instructors should make sure that learners are aware of not using multimodal features to communicate meaning, or even disable these features altogether.

Third, the present paper has a methodological contribution by outlining how an iterative design approach can advance concept mapping by constantly evaluating and enhancing methodological contributions. The identified functions are derived from user research and discussions with experts, closely aligned with real-life uses of multimodal features in concept maps. They are, furthermore, open for continued iterative enhancements, for example, by adding new functions or adapting functions in case they turn out to be misleading. Such a design process can advance the method of concept mapping.

12.6.3 Next Steps

While the guidelines and scoring rubric reported in the present paper build on empirical results and three design iterations with encouraging suggestions, they are still at a preliminary and exploratory stage. Two additional enhancement steps are required:

- a) investigate the usefulness of the guidelines and scoring rubric by collecting feedback from learners and instructors (for example, with a class in a realistic school setting or with workshops involving instructors) and by investigating how the identified principles affect creation and studying of concept maps, for example, by investigating whether they help build coherent concept maps (Gehl, 2013; Schumacher, 2009);
- b) a systematic study on the reliability of the scoring rubric, for example, by comparing concept maps that were created with and without the guidelines or by verifying interrater agreement of the scoring rubric.

Unfortunately, the planning of these steps was interrupted by the Covid-19 crisis, especially because it became impossible to gather a group of instructors to co-create instructional materials, given the increased workload of instructors during the pandemic. Although I am currently thinking about alternative ways to perform the follow-up research, the current paper cannot reach a state beyond a work-in-progress. However, the developed materials are valuable contributions to the concept mapping community: providing them as open access might allow other researchers and instructors to adapt them to their needs. For example, Safayeni et al. (2005) proposed to use circular links with plus and minus symbols to denote dynamic propositions in concept maps. Similar adaptations could be possible for other domains and research interests. Such adaptations and scholarly discussions could be incorporated in an enhanced future version of the materials, making them more versatile and ultimately establishing a "multimodal grammar" for concept maps in different domains.

Furthermore, work is ongoing on a fourth section of the guidelines and scoring rubric, currently labeled "multimodal features in concept mapping". This fourth section applies findings from other scholarly work to concept mapping, for example, by outlining how typography creates meaning (Serafini & Clausen, 2012). Section 4 is beyond the scope of the present paper because it largely consists of applying findings rather than contributing original research.

PART VI:

General Discussion

13 General Discussion

Education is currently facing tremendous challenges. Education is increasingly concerned with structural knowledge (Jonassen & Marra, 1994), meaningful learning (Novak & Gowin, 1984), and the development of so-called "21st-century skills" (Binkley et al., 2012; Mayrath et al., 2012; Nicol & Macfarlane-Dick, 2006; Redecker & Johannessen, 2013; van Laar et al., 2017). Concept mapping is a promising method to address these challenges, and digital concept mapping has a range of advantages (Anderson-Inman et al., 1998; Bruillard & Baron, 2000; Hwang et al., 2012). However, additional challenges arise as education becomes increasingly digitalized: Learners are becoming users (Ramiel, 2019), increasing the relevance of human-computer interaction (HCI) for digital education. HCI has ushered in a new perspective on digital education: Instead of "learning from technology", it is now about "learning with technology" (Jonassen & Marra, 1994; Salomon et al., 1991). Such a view allows for (a) investigating the impact of technology on educational processes and (b) purposefully shaping these processes through design and development.

The present dissertation contributes to such a perspective by drawing upon the notion of user experience (UX). Specifically, it addressed the following overarching research objective:

How can a user experience-driven approach contribute to digital concept mapping?

I addressed this research objective from two perspectives: that of the *tool* and the *experience* of digital concept mapping. I will outline and synthesize these perspectives in the following general discussion.

13.1 From Tool to Experience: Summary and Discussion

This dissertation starts with the formulation "From Tool to Experience", indicating a shift in perspective from thinking about a concept mapping tool to thinking about a concept mapping experience. This formulation should not be understood as a design process that moves from the tool to the experience: In line with Hassenzahl (2010), my dissertation followed the idea of considering the experience from the first moment of design, ultimately aiming at purposefully shaping the product to allow for positive experiences.

13.1.1 The Tool: Defining and Designing a Concept Mapping Tool

In establishing a user experience perspective on digital concept mapping, the present dissertation has outlined the role of pragmatic aspects (instrumental "do-goals") and hedonic aspects (non-instrumental "be-goals") of user experience (Hartson & Pyla, 2012; Hassenzahl, 2010; Lallemand & Gronier, 2018). Numerous studies contributed to identify users' do- and be-goals. The studies in Part II investigated functionalities and characteristics of digital concept mapping tools through a human-centered approach. I involved users directly in the project's early phases, specifically the exploration & analysis and ideation phases (Part II). The studies found that learners and instructors have concrete expectations in terms of functionalities and characteristics, which in turn determine whether learners and instructors are able to successfully implement concept mapping in their educational activities. Based on these concrete expectations, I collected and prioritized requirements (Part II) and incorporated the most important findings into several design iterations (Part III), building on prior work by Katja Weinerth (2015) and Eric François. This allowed me to refine a digital concept mapping prototype and derive further recommendations for future design.

Numerous results suggested a strong interest in concept map-based assessment for such purposes as assessing structural knowledge (Chapter 3) or providing learners with relevant feedback for self-regulated learning (Chapters 3 and 4). However, these use cases depend on being able to "read" and score concept maps, which users identified as a key concern (Chapter 3). Thus, I conducted a systematic literature review of concept map scoring and used our findings to derive a comprehensive framework, which I further converted into guidelines for instructors and researchers (Chapter 10).

Finally, I performed a study measuring the impact of user experience on digital concept mapping (Chapter 11). I found strong evidence that user experience impacts intention to use, supporting the central role of user experience as a quality criterion for digital products. I will return to the relations between user experience and the other measured variables in the study in Chapter 11 (psychological needs and scores) later in this general discussion.

13.1.2 The Experience: Researching and Shaping the Experience of Digital Concept Mapping

When investigating the research question of "how user experience contributes to digital concept mapping", my focus inevitably turned to the "be-goals" of digital concept mapping in order to answer *why* learners and instructors create concept maps (Hassenzahl, 2010). I investigated this question from several angles.

13.1.2.1 Hedonic Qualities of Digital Concept Mapping

First, in numerous studies making up the present dissertation, I found evidence for be-goals during interactions with the digital concept mapping tool, particularly with respect to the hedonic qualities of our investigated prototypes. I was able to make concrete design recommendations g for enhancing these hedonic qualities (see Chapter 9). In particular, the evidence suggests that the following enhancements could contribute to higher hedonic quality in digital concept mapping:

- eliminate potential sources of frustration (e.g., frequent mode switching, auto-alignment of links),
- prototype optimizations for touchscreen-based interaction (e.g., gesture support, enhanced freehand drawing),
- provide support for multimodal features, and
- create engaging, playful aesthetics.

These recommendations are based on evidence from numerous studies under different conditions (see Chapters 7, 8, and 11). Furthermore, due to the prominence of multimodal features, I systematically investigated the role of multimodal features in digital concept mapping (Chapter 12) by identifying use patterns and deriving guidelines for use and scoring of these multimodal features.

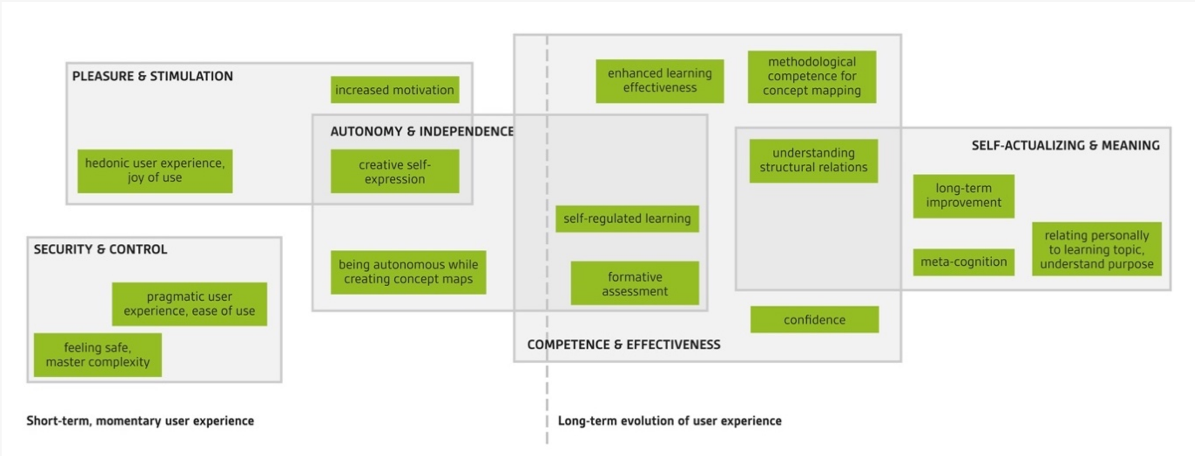
13.1.2.2 Contexts and Deeper Reasons for Digital Concept Mapping

Second, a user experience perspective on digital concept mapping is not limited to the aforementioned evaluations and recommendations, but also investigates the deeper reasons and contextual factors that impact the experience of concept mapping (Roto et al., 2010). Consequently, several studies contributed to defining these contextual factors for digital concept mapping, each with a particular focus. The studies in Part II addressed contexts and deeper reasons from various angles, such as identifying which educational activities will integrate concept mapping (Chapter 3) and what desired outcomes and pain points it will need to address (Chapter 3). I found clear evidence that concept mapping can help learners see the connections to addressing the contemporary educational challenges outlined in the introduction to the present dissertation. Finally, I found a strong need for a digital concept mapping tool and investigated our prototypes under different contextual conditions. The evidence suggests that these contextual factors affected users' evaluations of the prototypes: Especially in complex task settings (e.g., unrestricted concept mapping in Chapter 8 or the demanding task in Chapter 11), users were sensitive to additional difficulties imposed by the tool design (e.g., issues of pragmatic user experience). These findings provide strong support for the need for a human-centered, user experience-driven design perspective to ensure that tool design meets users' expectations in various contexts.

13.1.2.3 Towards a Profile of Psychological Needs for Digital Concept Mapping

Third, theories of user experience have long suggested the vital role of psychological needs in creating meaningful positive experiences and fulfilling be-goals (Hassenzahl et al., 2010; Hassenzahl et al., 2013). Consequently, three studies in the present dissertation investigated psychological needs in concept mapping. Chapter 4 identified psychological needs in digital concept mapping from an anticipatory perspective in interviews. Chapter 8 identified fulfillment of psychological needs in a particular use situation, namely the unrestricted creation of a concept map. Chapter 11 investigated the explanatory power of need fulfillment for pragmatic and hedonic user experience. In the following section, I will synthesize these findings into a profile of psychological needs for digital concept mapping and discuss possibilities for designing positive experiences (Desmet & Fokkinga, 2020; Desmet & Hassenzahl, 2012). Fig. 70 presents a psychological needs profile for digital concept mapping. It differentiates between the five main psychological needs and their driving factors. Furthermore, it distinguishes between short-term user experience (during or immediately after interaction with a digital concept mapping tool) and the long-term evolution of user experience. I will concentrate on findings that relate to individual concept mapping because collaborative concept mapping constitutes an area of future work.

Fig. 70: Theoretical psychological needs profile for digital concept mapping



Pleasure and stimulation refer to the impression "that you get plenty of enjoyment and pleasure rather than feeling bored and understimulated in life" (Sheldon et al., 2001, p. 339) and were the most prominent need in the study in Chapter 4. They were mainly associated with being motivated and hedonic user experience. Unsurprisingly, fulfillment of pleasure and stimulation had a high explanatory power for the hedonic dimension of user experience (Chapter 11). While "having fun" is arguably not the core of a concept mapping experience, pleasure and stimulation have an important mediating or enabling function for digital concept mapping: A joyful-to-use concept mapping user interface and stimulating instructions should increase users' motivation to engage in concept mapping and ultimately favor successful learning. As such, evidence suggests that the need for pleasure plays an important role in momentary user experiences, often similar to flow experiences (Csikszentmihalyi, 2008) (see Chapters 4 and 8). Thus, designers should explore creating such joyful and stimulating moments in users' interactions with digital concept mapping tools. Participants in the study in Chapter 8 emphasized creative self-expression as another important source of joyful experiences in digital concept mapping, and Chapter 12 addressed this by providing guidelines that align such creative self-expression with meaningfully using multimodal features in concept maps. Chapter 8 further found that issues with pragmatic user experience hinder the fulfillment of pleasure and stimulation.

Security and control refer to the impression that you are "safe and in control of your life rather than feeling uncertain and threatened by your circumstances" (Sheldon et al., 2001, p. 339). In Chapter 4, the need for security and control was mainly associated with notions of mastering complexity and not feeling lost when new insights into a topic or problem create an impression of de-stabilization (in the sense of becoming unsure of aspects one has previously not called into question). Security and control played a prominent role in explaining variance in pragmatic UX (see Chapters 8 and 11). This finding is in line with the notion of being in control of one's interaction with the concept mapping tool, which is a requirement for successfully reaching pragmatic "do-goals" (Hassenzahl, 2010). Interestingly, the idea of being in control of the interaction did not appear in the study in Chapter 4, potentially indicating that users take this notion for granted. This finding is in line with views of security and control as a "deficiency need, i.e., a need that creates negative affect if blocked, but not necessarily strong positive feelings if fulfilled" (Hassenzahl et al., 2010, p. 358). When such needs are not fulfilled, they might impact user experience negatively (e.g., when learners do not feel in control of their interactions), but fulfilling these needs might not in and of itself create positive user experiences in digital concept mapping[32]. However, there might also be some motivational factors associated with security and control. For example, Erdogan (2009) suggested that digital concept mapping might support feeling in control of concept map creation (because it is easier to adapt elements) and ultimately lead to higher involvement. Thus, security and control in concept mapping seem to be closely associated with situational factors: They do not create particularly positive experiences, but have a significant negative impact on momentary experiences when left unfulfilled. Designers should favor functionalities that make users feel in control of the interaction by providing undo and redo functionalities, auto-saving, and making it possible to adapt any feature of the concept map (including the flow of link lines).

Autonomy and independence refer to the impression that "you are the cause of your own actions rather than feeling that external forces or pressures are the cause of your actions" (Sheldon et al., 2001, p. 339). In Chapter 4, these needs were mainly associated with longer-term effects like self-regulated learning, often in the context of formative assessment and feedback to help learners become aware of (and ultimately address) their knowledge gaps. These were also key concerns for the participants in the study of Chapter 3. Autonomy and independence were associated with momentary aspects of experience, particularly a feeling of independence during concept map creation. However, participants did not give the need for autonomy and independence a prominent role overall. This differed in the study in Chapter 8, where participants frequently associated their concept mapping experience with autonomy and independence, lending support to its strong role in defining momentary user experience. In Chapter 11, autonomy and independence had the highest explanatory power of all needs for both the pragmatic and hedonic dimensions of user experience. Numerous suggestions in the study in Chapter 2 were associated with freedom and creativity, particularly a wide selection of multimodal features in concept maps (which, in turn, was related to the need for pleasure and stimulation). These results suggest that feeling autonomous and independent strongly supports a positive user experience. Thus, designers should emphasize functionalities that create these feelings, for example, by allowing users to set personal preferences and adapt as many aspects of their concept maps as possible. Longer-term effects like self-regulated learning might be facilitated by formative assessment functionalities, for example, a personal dashboard with comprehensible, useful diagnostics of one's learning progress and suggested areas for improvement.

Competence and effectiveness refer to the impression "that you are very capable and effective in your actions rather than feeling incompetent or ineffective" (Sheldon et al., 2001, p. 339). Competence and effectiveness had explanatory power for the pragmatic dimension of user experience, given their

[32] I deliberately add "in digital concept mapping" here because I am not sure whether this finding generalizes to other areas. For example, in areas that are more security-critical than digital concept mapping, fulfillment of the need for security and control might create positive experiences.

relation to the instrumental goal of effectiveness of learning (see Chapter 8). However, they were also associated with eudaimonic aspects of personal growth, particularly with acquiring methodological competence in concept mapping (which is not yet established in Luxembourgish secondary education, see Chapter 3) and with being able to structure complexity in a way that facilitates understanding (see Chapters 2, 3, 4, and 8). Competence was strongly associated with understanding structural relations (see Chapters 4 and 8). The relation to learning suggests that competence and effectiveness are needs that most likely evolve over time. However, design might also create momentary feelings of need fulfillment (resulting in confidence, see Chapter 8), for example, by making learners aware of how their knowledge has grown or supporting the impression of having a structured overview (e.g., nesting complex concept maps in one another to avoid feeling overwhelmed). Designers can also support competence by implementing useful help functionalities and instructional materials to aid learners in acquiring concept mapping competence.

Self-actualizing and meaning refer to the impression "that you are developing your best potentials and making life meaningful rather than feeling stagnant and that life does not have such meaning" (Sheldon et al., 2001, p. 339). These needs were mainly associated with eudaimonic aspects of relating personally to a learning topic and meta-cognition, but did not play an important role in the study in Chapter 4. Likewise, they had some explanatory power for the pragmatic and hedonic dimensions of user experience (see Chapter 11) but were not central to explaining these findings. The recent framework on "meaning" by Mekler and Hornbæk (2019) might help understand the role of the needs for self-actualization and meaning. This framework identifies five components of meaning, which might not have been strong enough in our studies (for example, because participants did not feel a high degree of connection to the topic of the study in Chapter 11). The needs for self-actualization and meaning are future-oriented, which suggests that they might evolve when learners use concept mapping repeatedly and become more aware of how it supports their personal growth in the long run (supported by the emphasis that participants put on long-term, continuous improvement in Chapter 8). The meaning framework can also be used to infer design recommendations to better fulfill the needs for self-actualization and meaning (Mekler & Hornbæk, 2019). Accordingly, positive experiences in digital concept mapping are more likely when the tool inspires learners to see the value of concept mapping for their future. For example, design elements like prompts, functionalities for the autonomous use of multimodal elements, or motivating learners to create concept maps for topics that are important to them might encourage learners to actively relate the field of concept mapping to themselves (contributing to a feeling of connectedness) or highlight the value of concept mapping (contributing to a feeling of significance).

Relatedness and belongingness refer to the impression "that you have regular intimate contact with people who care about you rather than feeling lonely and uncared for" (Sheldon et al., 2001, p. 339) and were mainly associated with semantic and social relations in the studies in Chapters 4 and 8. **Influence and popularity** refer to the impression "that you are liked, respected, and have influence over others rather than feeling like a person whose advice and opinions nobody is interested in"

(Sheldon et al., 2001, p. 339) and were mainly associated with the positive aspect of helping others but also with negative aspects that bias discussions in collaborative concept mapping. Both social needs played a less prominent role in explaining variance in pragmatic and hedonic user experience in Chapter 11. However, the present dissertation deliberately focused on individual concept mapping given the early design stage of the investigated concept mapping tool. The limitations section will discuss this decision in detail.

This psychological needs profile can be applied to drive follow-up design iterations to enhance hedonic and eudaimonic experiences. However, it is currently still at a theoretical stage: Although grounded in empirical research, several open questions remain. For example, the design ideas to fulfill the respective needs still need to be empirically validated. Additional design ideas should also be investigated: For example, what would a concept mapping tool look like when it does not need to meet this project's conditions (i.e., embedded in an assessment platform, flexibility, building on prior work) but instead fully concentrates on fulfilling a particular need, say pleasure? Furthermore, several needs were theorized to have a longer-term impact on user experience, but the longer-term development of user experience was not investigated in the present dissertation (see Section 13.4 on "Future Work"). Finally, the suggested needs profile is based on user research but was itself not created through user research. Thus, it would be interesting to verify it with users: Do they agree with its propositions? Do they see areas for improvement? Could the needs profile itself serve as a design inspiration, with users in co-design workshops specifically designing a concept mapping tool to fulfill a particular need?

13.2 Reflecting on User Experience in Education

The present dissertation outlined how a user experience perspective can contribute to digital concept mapping. However, in my view, a dissertation on user experience should also reflect on the very notion it is based on, particularly when questions have been raised that might contribute to sharpening the definition of user experience. Two such questions are particularly important in the present dissertation. The first concerns the different roles of stakeholders in digital concept mapping and what these mean for the user experience concept. The second concerns the relation between user experience and the overall purpose of education.

13.2.1 On the Role of Designers, Developers, Learners, and Instructors and the Nature of experiences

A user experience perspective on digital concept mapping changes the role of designers and developers: Their task is not only to create a *tool* that allows learners to achieve an instrumental goal like creating a visual representation that resembles a concept map. Their task, instead, is to purposefully shape *experiences* with such a tool within educational activities. One of the original contributions of the present dissertation is to establish how user experience shapes these educational activities and how user experience can provide a deeper understanding of digital concept mapping. However, user experience poses two fundamental questions about the role of different actors in education.

First, when user experience becomes a key quality criterion for users, user experience design also becomes a key development criterion. This poses challenges for the development of digital tools for learning and education: Should every project now involve a UX designer and UX researcher? How can awareness of user experience-related questions be raised in other professions, such as among developers (a concept generally known as "UX maturity"; Lacerda & von Wangenheim, 2018; Molich et al., 2020; Sauro et al., 2017)? How can user experience be balanced with other project requirements? These are difficult questions to answer. I argue that the human-centered design process (Hartson & Pyla, 2012; Lallemand & Gronier, 2018) outlined in the present dissertation could potentially drive the overall development process for digital products, similar to other suggestions regarding product development (Ries, 2014): Research could identify requirements, design could create solutions and prototypes, and development could implement the successful solutions. However, these different work areas would probably need to be deeply integrated with each other. For example, designers might need help from developers in order to prototype specific functionalities.

Second, it is important to emphasize that *user experience* is not the only dimension that impacts learners' experiences with digital concept mapping (or any technology). Instead, experiences with digital learning technologies are influenced by the technology, the instructor, the task, the instructional content, the learners, and their social relation. In light of such complexity, the question of "how to design for positive experiences in learning with technology" becomes more complicated. What should be the role of technology (and how can this be designed for) when even the holistic concept of user experience does not capture all the influences that shape experiences? Do researchers and designers need to examine different kinds of experiences, like "user experience", "content experience" and the like? If yes, how are these related to one another? Alternatively, the term "human experience" (HX) has recently drawn attention, most prominently in the applied design field[33] but also in research (Fisk et al., 2020). However, a new term is not without its challenges: It makes the complex construct of user experience even more complex and is probably still not inclusive enough, particularly with respect to the field of education, the goal of which is not only optimal human experience, but also aspects that go beyond the human perspective (e.g., sustainability). Or should researchers and designers introduce a term like "learning experience"? However, would such a term solve the issue mentioned above? Moreover, how would researchers and designers address the challenges posed by such a term, questions like "what is the difference between user experience in learning and user experience in another area of technology"?

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[33] See, for example, the blog post by Ky Pham (2019, https://uxdesign.cc/hx-human-experience-we-all-should-keep-it-in-mind-to-create-more-value-82d760bc5eae), the presentation on the 77 Human Needs System by Guido Beier (2021, https://youtu.be/lr3cRrS3hXs), or Apple's job postings for software and services (https://www.apple.com/careers/us/software-and-services.html).

13.2.2 User Experience and the Purpose of Education

A user experience perspective on digital concept mapping takes a broad view of the goals of learners and instructors, including their instrumental and non-instrumental goals (Hassenzahl, 2010; Thüring & Mahlke, 2007). Many of these goals relate to aspects of learning and creating motivation for learning (see Chapter 1), often in relation to eudaimonic aspects like becoming more competent (see the needs profile discussed in Section 13.1.2). Such a shift to eudaimonia in HCI (Stephanidis et al., 2019) necessarily involves asking difficult questions: What precisely is the purpose of concept mapping in education, and how could a tool support this purpose? Given its interdisciplinary focus, the present dissertation addressed this question mainly from the perspectives of cognitive psychology and human-computer interaction. However, alternative views exist. For example, Biesta (2009) and Ramiel (2019) criticized the focus on "learning" for not adequately addressing social, cultural, and political aspects of education. In line with this, the notion of the "user" is criticized for de-emphasizing such educational questions (in favor of technological or economic questions; Ramiel, 2019). In line with the humanities tradition within education (Terhart, 2018), Biesta (2009, p. 25, italics in original) identified qualification (having the knowledge and skills required to assume a particular role), socialization (becoming a member of society), and subjectification (becoming an independent person with subjective characteristics) as "*ultimate* values: values about the aims and purposes of education". For Biesta (2009), the focus on learning ("learnification", in his words) does not adequately address these purposes because it focuses on the individual and does not adequately address the content of what is being learned.

Although the present dissertation strongly focused on learning and assessment, some of the results are of relevance for the educational purposes mentioned above, particularly the hedonic and eudaimonic results: Concept mapping was associated with aspects like learning effectiveness, but was not limited to this. Instead, learners and instructors expressed needs like increasing their competence, understanding others' perspectives and how society functions, and meta-cognition as overarching "be-goals" (Hassenzahl, 2010). In the present dissertation, I could not investigate or design for all of these areas, as the digital concept mapping tool was at an early stage of development and much work was needed to define the tool objectives and implement essential features of digital concept mapping. However, the importance learners and instructors ascribed to hedonic and eudaimonic goals motivated me to more closely consider the discussions mentioned above. Could a concept like user experience contribute to bridging these different views on education, precisely because it empowers learners and instructors to take an active role in shaping technology (and their experiences with it), thus addressing both instrumental and non-instrumental goals (Hassenzahl, 2010; Thüring & Mahlke, 2007)? Admittedly, such an approach would need to go beyond the focus on co-designing a tool outlined in the present dissertation and take a much stronger political and societal perspective on the entire experience and purpose of digital education, similar to approaches associated with the term "participatory design" (Hansen et al., 2019; Kankainen et al., 2012; Muller & Druin, 2012). However, would the spirit of such an investigation not be similar to the present dissertation, contributing to advancing digital technology to achieve goals that go beyond effective learning and assessment?

13.3 Contributions

The present dissertation is multidisciplinary and contributes to the research fields of human-computer interaction (HCI) and concept mapping, specifically from a cognitive or educational psychology perspective. Furthermore, it has a strong applied design focus, proposing recommendations for the design of a digital concept mapping tool and instructional guidelines for successfully using it in educational activities, all with the goal of creating positive experiences in digital concept mapping. I will outline these contributions following suggestions by Wobbrock and Kientz (2016). Specifically, I distinguish between empirical, theoretical and meta-analytical, methodological, and artifact contributions.

13.3.1 Empirical Contributions

The primary objective of this dissertation was to empirically define how a user experience-driven approach contributes to digital concept mapping. Consequently, three studies in Part II took a human-centered perspective to define main objectives of user experience design for digital concept mapping, discussing potential functionalities and characteristics of the tool, contextual factors, and the psychological needs involved. These studies were used to generate an empirically derived requirements profile for UX design in digital concept mapping.

Two studies in Part III systematically demonstrated how to design for these requirements, building on prior work by Katja Weinerth (2015) and Eric François. The studies provided insights into how the design of a concept mapping tool impacts user experience, particularly with regard to the fulfillment of psychological needs.

Finally, Part V empirically validated the impact of user experience on digital concept mapping. Chapter 11 found strong empirical support for the fundamental role of psychological needs fulfillment in user experience. It found that user experience had a high explanatory power for intention to use, thus establishing user experience as a key concern in the adoption of technology. Furthermore, it found evidence that user experience might be related to assessment scores, suggesting a need for further research to investigate how the design of digital tools impacts learning and assessment success. Finally, Chapter 12 provided insights into the uses of multimodal features in digital concept mapping. In summary, the empirical findings of the present dissertation contribute to establishing user experience as a key construct to consider when creating digital technologies for education, which is only gaining in importance as educational activities become increasingly digitalized.

13.3.2 Theoretical and Meta-analytical Contributions

An overarching theoretical contribution of the present dissertation concerns psychological needs in concept mapping, which is relevant in light of their importance for positive user experience (Hassenzahl, 2010; Hassenzahl et al., 2010; Hassenzahl et al., 2013). I systematically contributed to such research from several angles, including anticipated concept mapping (Chapter 4) and realistic concept mapping (Chapters 8 and 11). While these results were empirical in nature, I ultimately synthesized them to generate a theoretical psychological needs profile (Desmet & Fokkinga, 2020) for digital concept mapping. I also made suggestions for further studies and outlined how the postulated needs profile could inform product design.

Furthermore, Chapter 10 provided a systematic literature review of criteria used to score concept maps. We synthesized this research into a comprehensive framework, identifying three dimensions, clarifying their relationship, and outlining areas for future research, such as the use of multimodal features to score and analyze concept maps.

13.3.3 Methodological Contributions

Although not its main focus, the present dissertation also made several methodological contributions. The studies in Part II demonstrated how to systematically involve instructors and learners in a human-centered design process, even at a stage before prototype testing. Chapter 2 identified a methodology for combining functionality-driven and experience-driven design by directly involving participants as co-designers (Druin, 2002). Chapter 3 discussed how co-creative storytelling can help participants share their ideas about using digital concept mapping in their educational activities.

Drawing upon numerous findings on the prominent role of multimodal features for positive user experience in digital concept mapping, the study in chapter 12 generated guidelines and a scoring rubric to support the meaningful, intentional use of multimodal features in concept maps, thereby addressing a research gap identified in our systematic literature review (Chapter 10). In addition to its methodological contributions, this work also advanced the theoretical discussion on concept mapping by drawing connections to the fields of multimodality and human-centered design, which could potentially serve as a starting point for further research into the multimodal "grammar" of concept maps.

13.3.4 Artifact Contributions

All studies in the present dissertation contributed findings to inform the design of digital concept mapping tools. The studies in Parts II, III, and V contributed to validating a flexible, feature-rich concept mapping tool that is adapted to specific conventions on different technologies, such as touchscreen optimizations. Three studies (Chapters 7, 8, and 11) investigated iterative improvements of concept mapping prototypes and derived several design recommendations (Chapter 9). Finally, this work makes several applied contributions for instructors and researchers. The comprehensive framework of criteria for scoring concept maps (Chapter 10) was converted into guidelines, providing a useful synthesis for instructors and researchers to decide and reflect on their scoring methodologies (available as an online supplement, see https://rohl.es/dissertation). I also converted my methodological findings on the use of multimodal features in concept maps into guidelines and a scoring rubric. I intend to continue working on these materials in the future by validating and investigating their usefulness for instructors. I am also planning to integrate this work into the OASYS assessment platform to make concept map scoring available to instructors.

13.4 Future Work and Limitations

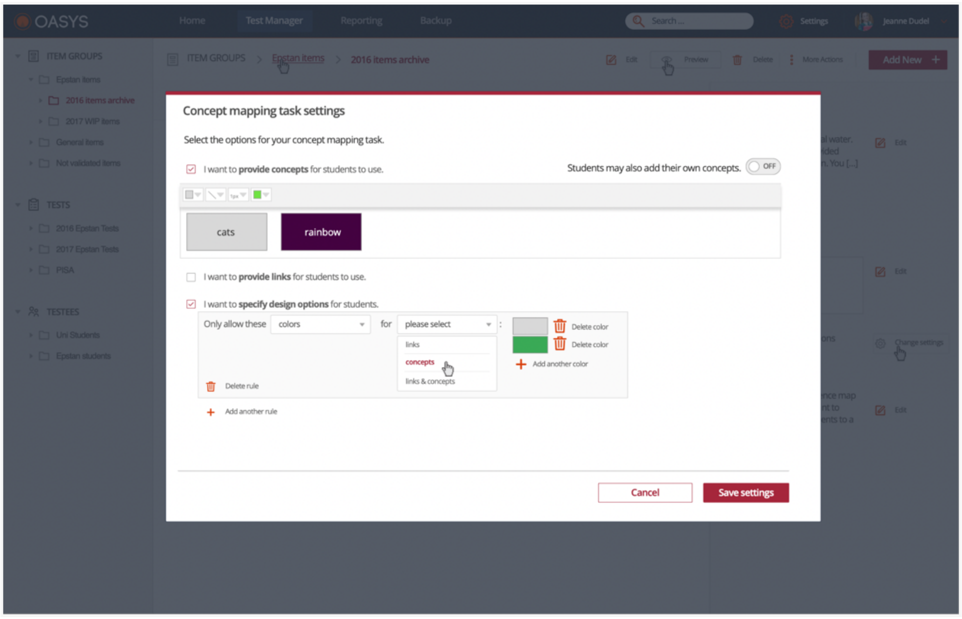
Although the present dissertation has contributed to the above-mentioned research areas, it has also highlighted avenues for future research and is not without its limitations. Five open questions need to be discussed.

First, the present dissertation sought to extend a previous PhD project by Katja Weinerth (2015) by building on her research results. While the studies making up the present dissertation found valuable solutions to enhance user experience, not all issues have been resolved. The proposed design recommendations require significant further design efforts. Human-centered design is iterative and requires constant evaluation and adaptation (Hartson & Pyla, 2012; Lallemand & Gronier, 2018). The design recommendations to address open issues outlined in the present dissertation are no exception: While grounded in research, they must still be thoroughly investigated to verify whether they reach their respective goals.

Furthermore, requirements external to experience design also need to be considered, such as technical feasibility and available development resources. An integrated team including designers, developers, instructors, and researchers should work to find this balance. The establishment of such a team is not an easy task, particularly because different schedules need to be aligned (e.g., research schedules and development roadmaps). However, given the growing importance of digital technology in education, such teams could provide a solid foundation for creating prototypes and evaluating the proposed design recommendations.

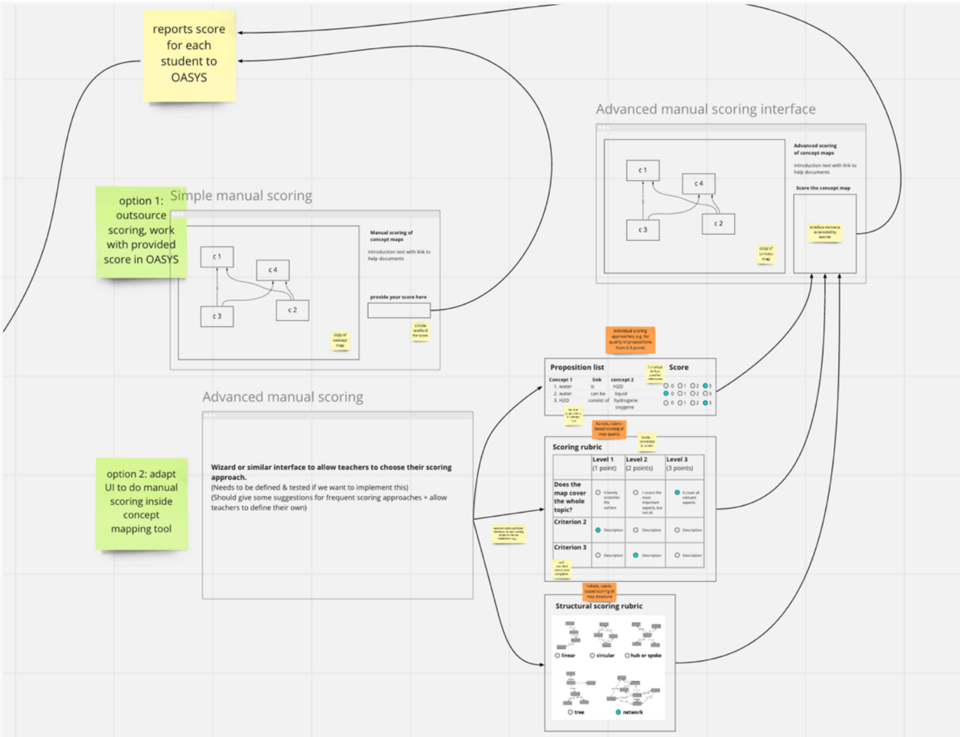
Second, a future human-centered design iteration should concentrate on systematizing work on interfaces for instructors. The early stage of the prototype under study made it impossible to create a functional prototype of interfaces for setting up or scoring concept mapping tasks (instructor back-end), but early design work and evaluation have been performed. For example, a promising wizard-style mockup (allowing users to specify terms and options for concept mapping tasks; see Fig. 71) was tested during the study in Chapter 7 with four instructors. The mockup was evaluated very positively by the instructors and could be enhanced based on the task taxonomy identified in Chapter 10. Likewise, early sketches for scoring interfaces were created (see Fig. 72)[34]. Work remains to be done on creating and testing functional prototypes of these ideas, thus ensuring that the instructor back-end interfaces also provide a positive user experience.

***Fig. 71**: Wizard-style mockup for creating concept mapping tasks*



[34] At the time of writing, co-design workshops with instructors are currently being planned with the aim of involving instructors in creating solutions for concept map scoring and concept mapping tasks. However, I was not able to conduct these workshops before submitting the present dissertation.

Fig. 72: *Early sketches for scoring interfaces*



Third, future work could include objective measures of human-computer interaction (e.g., number of clicks, time on task, or errors during the interaction) – via log files[35], for example – in addition to subjective measures of user experience. Chapter 1 argued that user experience is important for digital concept mapping because it might impact scores, but the study in Chapter 11 found only partial support for this claim (i.e., the linear regression models were only significant on tablets, with their lower overall user experience, and the R^2 values were relatively low). These findings are only partially in line with the impact of usability on scores described by Weinerth (2015). These findings could be related to the subjective nature of user experience (Roto et al., 2010): It is possible that subjective impressions do not match objective results. For example, a tool might *feel* efficient but not necessarily *be* efficient. Furthermore, the term "experience" also points out that users' *past* impacts their current evaluations (Roto et al., 2010): What a user evaluates as efficient necessarily depends on which other tools the user has used in the past. Thus, a user might interpret something as efficient that in fact is relatively inefficient, simply because the user is not aware of more efficient alternatives.

Fourth, an open question relates to the temporal nature of user experience. User experience encompasses anticipated experience (before use), momentary experience (during use), episodic experience (after use), and cumulative experience (with repeated use over a longer period; Roto et al., 2010). The studies

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[35] I considered including an analysis of facial expressions as an example of such objective measurements. I attempted to use facial expressions to derive information about momentary emotional experiences, based on basic emotion theory (McDuff et al., 2016; Clark et al., 2020; Ekman, 1992; Keltner et al., 2019; Cohn et al., 2007). However, recent discussions on the validity of deriving emotions from facial expressions made it impossible to include this research in the present dissertation (Barrett et al., 2019).

in Part II were primarily concerned with anticipated experiences of digital concept mapping, while the studies in Part III combined measures of momentary experience (e.g., thinking aloud or the critical incidents technique) and measures of episodic experience (e.g., debriefing interviews and questionnaires). However, some of the hedonic and eudaimonic qualities of experience are likely to reveal themselves over time because learners increasingly realize how concept mapping contributes to their personal growth. Thus, the present dissertation lacks an evaluation of cumulative experience with digital concept mapping, which will only be possible after the roll-out of the digital concept mapping tool. The broader context in which the present dissertation was embedded, specifically the connections to the country-wide platform OASYS and support by the project's funding partner SCRIPT, provides a promising setting for such research. Longitudinal qualitative and quantitative studies could investigate how user experience in digital concept mapping evolves over time.

Fifth and finally, user experience in collaborative concept mapping remains an area of future work. Collaboration was discussed in several studies, such as in the stories outlining uses of digital concept mapping (Chapter 3), functionalities to facilitate collaboration (e.g., rights management, sharing, or synchronous remote concept mapping capabilities; see Chapter 2), and the discussions of psychological needs (Chapter 4). Numerous suggestions related to collaborative learning were also made, particularly that collaboration might involve introverted learners, raise motivation and create pleasure, and build competence in understanding others' perspectives. Collaboration should also support creativity (Glăveanu, 2018; Stephanidis et al., 2019), making it a core concern for society. Unsurprisingly, collaborative concept mapping is frequently discussed in the literature (Basque & Lavoie, 2006). However, because the project is still at an early phase, the scope of the present dissertation was limited to individual concept mapping, which should be able to provide a solid foundation for later investigations of collaborative concept mapping. The roll-out of the concept mapping tool in Luxembourgish schools could provide a good opportunity to investigate how collaboration affects user experience in digital concept mapping.

13.5 5.5 Conclusion

Education today faces tremendous challenges: In a society in which the amount of information is constantly growing and increasingly interconnected (Keller & Tergan, 2005), learners need competencies in seeing connections across domain boundaries and acquiring skills in meta-cognition and self-regulated learning (Novak & Gowin, 1984). At the same time, additional challenges like increasing multilingualism and diversity require ways to create a shared understanding (Basque & Lavoie, 2006; Newell & Proust, 2018). Generally subsumed under the umbrella term "21st century skills" (Binkley et al., 2012; Mayrath et al., 2012), these competencies are expected to help learners address the challenges mentioned above. Concept mapping is a promising method for addressing these challenges due to its focus on meta-cognition (Novak & Gowin, 1984), structural knowledge (Jonassen & Marra, 1994), and other 21st-century skills like systems thinking and complex problem-solving (Brandstädter et al., 2012; Hwang et al., 2014; Stoyanova & Kommers, 2002). Digital concept mapping extends the capabilities of concept mapping even further (Alpert & Grueneberg, 2000; Anderson-Inman et al., 1998; Bruillard & Baron, 2000; Hwang et al., 2012).

The shift to the digital medium, however, is itself a challenge, because the digital medium introduces additional requirements for addressing educational questions. The present dissertation suggests that user experience is one such additional requirement for two reasons. First, in the digital medium, learners and instructors have the additional role of users (Ramiel, 2019), and thus depend on the design of digital tools to reach their educational goals. If they have to expend too many cognitive resources on operating a tool (or even worse, completely fail to do so), their educational performance will be affected (Weinerth, 2015; Tselios et al., 2001; International Test Commission [ITC], 2006). Second, digital technology has itself evolved into a source of experiences beyond being a "means to an end" (Hassenzahl, 2010). Thus, designers of digital technologies for education need to ensure that these experiences are positive and support learners in reaching their educational goals (Hassenzahl, 2010). A user experience perspective on digital concept mapping integrates these two considerations in its pragmatic and hedonic dimensions (Diefenbach et al., 2014a; Hassenzahl & Tractinsky, 2006) and thus holds the promise to consider and balance both aspects.

The present dissertation investigated such a user experience perspective from several angles. It integrated users deeply in defining the directions of the project (Part II), validated several design iterations of a digital concept mapping tool (Part III), synthesized research on concept map scoring to address one of users' core concerns in our studies (Part IV), and measured the impact of user experience (Part V). In doing so, it has outlined how user experience shifts the design and research perspective from a *tool* to an *experience*. Furthermore, it has identified several insights into how designers, developers, educators, and learners can jointly shape the digital concept mapping experience.

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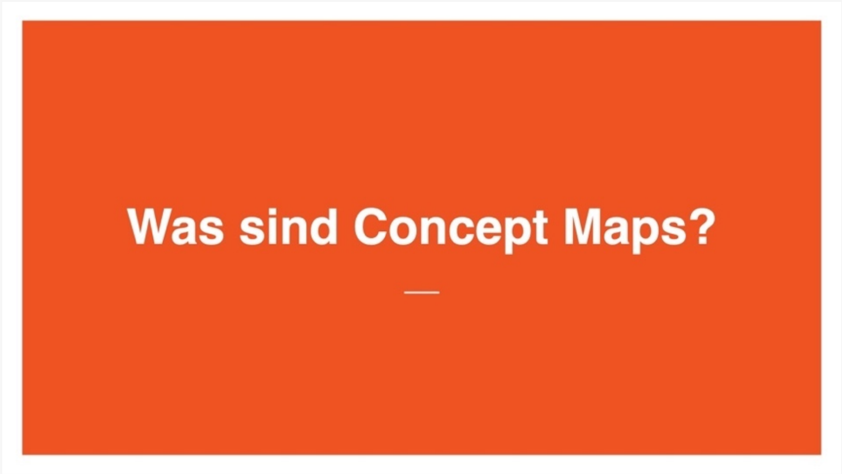
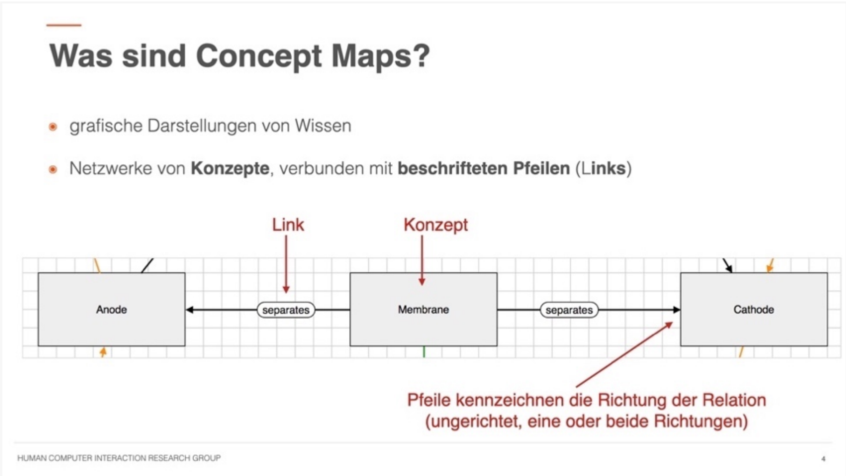
15 Appendix

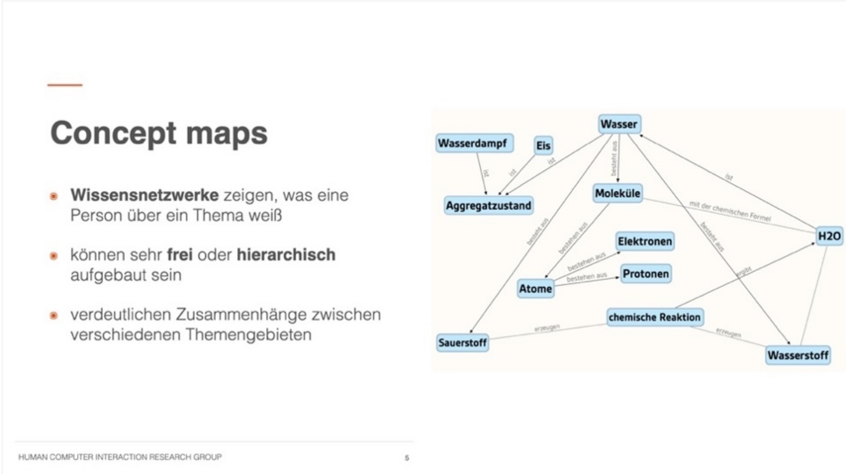
Appendix A: Introduction to Concept Mapping

Table 25 demonstrates how the participants were introduced to concept mapping in the studies described in Chapters 3 and 4.

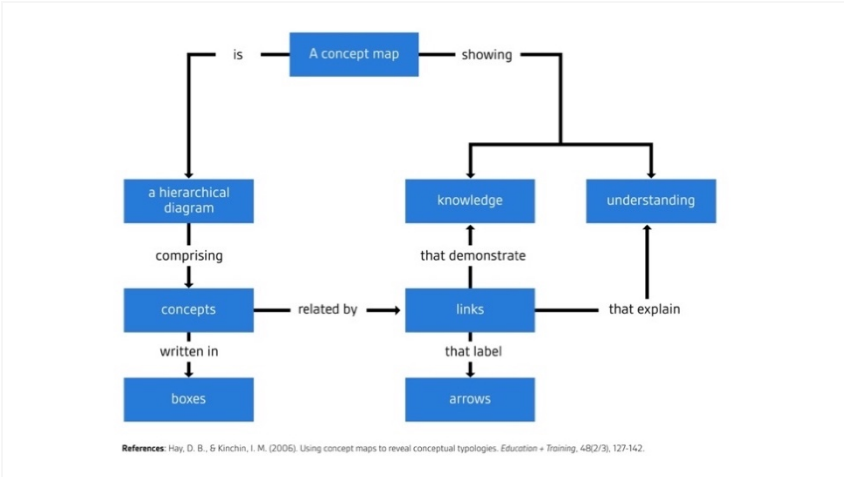
***Table 25**: introduction to concept mapping*

Description	Slide
Introduction: What are Concept Maps?	
Definition of concept maps, basic structure with concepts and labeled links	

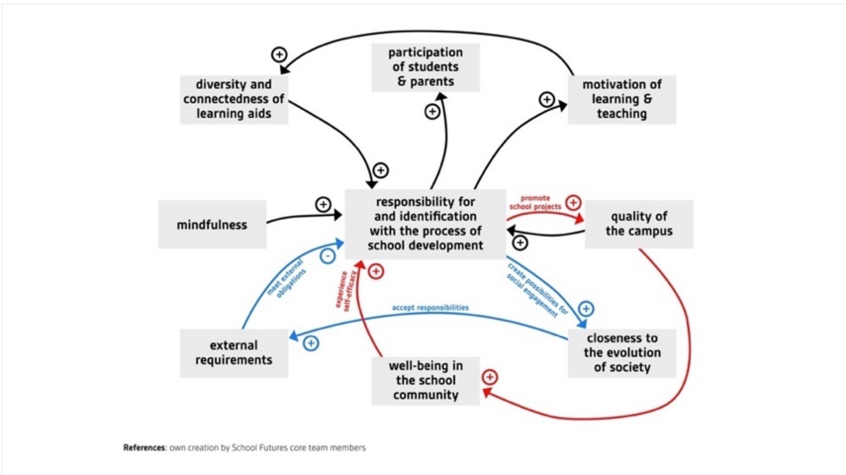
Details about concept maps as networks of knowledge, free or hierarchical structure, can cover multiple subjects example “concept map about water”

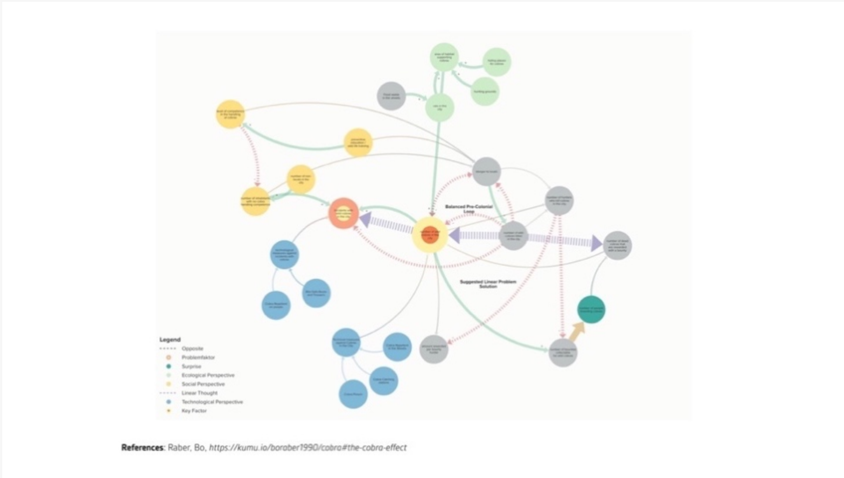


Example “hierarchical concept map”



Example “systems diagram” about the problem “How do we create responsibility for and identification with the process of school development?”



Example "systems diagram Cobra Effect"	
Wrap-up	Opportunity to ask questions about concept mapping and the examples

Appendix B: Benchmarking

The benchmarking contains (a) concept mapping tools, (b) mind mapping and diagram tools, and (c) other tools for digital education that participants mentioned in the studies of Part II.

Axon Idea Processor (AXON Research, http://axon-research.com/)

- ***description***: idea processor (representation similar to concept map)
- ***price***: free version (max. 20 items), 135 $ (full version)
- ***platform***: Windows, web-based (Axon JS)
- ***functionalities***: allows the use of icons in nodes; calculates some automated scores (Flesch, Kincaid Grade, Automated Readability, Coleman-Liau Index)
- ***interaction design***: based on drag & drop, using keyboard as modifier

Cmap Tools (Florida Institute for Human & Machine Recognition, https://cmap.ihmc.us/)

- ***description***: feature-rich concept mapping tool by Novak and his team
- ***price***: free (registration required, donations welcome)
- ***platform***: macOS, Windows, Linux, iPad, web-based (installation on own server), Cloud
- ***functionalities***: share maps with others, edit maps simultaneously, link resources in maps, create web pages from maps, menu for mathematical characters, extensive export functions, Cmap Recorder (records steps, allows to replay the creation of map), Presentation Builder (allows to add nodes to slides, then use concept maps as a presentation), text can be added as a mouse over
- ***interaction design***: relies on floating windows (for adjustments and options), lines: click icon, than drag to concepts; dragging lines in empty space automatically creates concept node

Compendium (Compendium Institute, http://compendium.open.ac.uk/)

- ***description***: concept mapping tool (uses legacy Java 6, so probably not that maintained at the moment)
- ***price***: free
- ***platform***: macOS, Windows, Linux
- ***functionalities***: nodes have labels and details (for descriptions); interesting onboarding (uses concept maps to explain concept maps & the software)

Cytoscape (S. National Institute of General Medical Sciences [NIGMS], https://cytoscape.org/)

- ***description***: Open Source network analysis tool
- ***price***: free
- ***platform***: macOS, Windows, Linux

- ***functionalities***: Cytoscape app store (with extensions), several style templates, allows free annotations to any part of the map
- ***interaction design***: unusual: right click on any place, then select from menu what to create

CS Global Max (Concept Systems Incorporated, https://www.conceptsystems.com/)
- ***description***: commercial web tool specialised in group concept mapping
- ***price***: from 1,200 €, various pricing models (based on license and work type)
- ***platform***: web-based
- ***functionalities***: cannot be judged due to the restricted access (free webinars are available), outline view and map view
- ***interaction design***: point & click, pre-defined symbols are dragged to the canvas (= semantic, e.g., pro or con node, argument node), corners of elements show information (e.g., lower left corner = weight)

Decision Explorer (Banxia, http://banxia.com/dexplore/)
- ***description***: commercial tool for cognitive mapping (more focussed on problem structuring)
- ***price***: from 99 pounds
- ***platform***: Windows
- ***functionalities***: not tested further

Go Conqr (Examtime Limited, https://www.goconqr.com/de/)
- ***description***: digital learning tool
- ***platform***: web
- ***functionalities***: courses, mind maps, quizzes, cards, notes, library of user-generated content"
- ***interaction design***: Onboarding (2 mins to personalize experience); IA using subjects, courses, content, groups; Overlay on first start (arrows and short texts show functions); possibility to add resources to elements; drag plus-sign away to create new node; WIMP style menu to change settings; different colour palettes (modern, pastel, original); player to visualize process of map creation; additional iOS-Web-App

iMindMap (iMindMap, https://imindmap.com/)
- ***description***: commercial tool for mind mapping
- ***price***: 80-250 €
- ***platform***: macOS, Windows, iOS
- ***functionalities***: include images in the mind map, presets for a variety of forms, time map view (position mind maps on a calender as a kind of hybrid between mind map and project management (seems very interesting), 3D view of mind maps

Insight Maker (MIT, https://insightmaker.com)
- ***description***: tool to express ideas and causal models
- ***price***: free
- **platform**: web
- ***functionalities***: allows to set characteristics of models, simulate their results; various functionalities specific to systems maps (e.g., identify feedback loops)
- ***interaction design***: scratchpad where people can draw

Inspiration (Inspiration® Software, https://www.inspiration-at.com)
- ***description***: visual thinking tool, combinging concept maps and mind maps
- ***price***: 35€
- ***platform***: macOS, Windows, iOS, web
- ***functionalities***: outline view, mindmap view, auto-format maps

kumu.io (Kumu Inc, https://kumu.io)
- ***description***: tool to create & present influence diagrams
- ***price***: from 9$ / month
- ***platform***: web
- ***functionalities***: shows a legend (which is a good idea!), holding the mouse on a concept for 1 sec fades all non-connected concepts to the background, concepts can be grouped, clicking a concept opens information about it, filter functions (e.g., groups of concepts), layout settings (e.g., dark & light

theme), templates for various maps (system map, stakeholder map, SNA, other), nice onboarding (little dots blink on buttons, clicking them opens tutorial)
- ***interaction design***: Material Design style with a Floating Action Button (+) which creates anything, you connect elements using labels ("x" to "y"), not directly drawing; also limited possibilities to change concepts; advanced editor (JSON style, but should be unusable for most users)

MaNet (Mannheim Research Company, http://www.marescom.net/products/manet)
- ***description***: uses CM based on the "Mannheimer Netzwerk Elaborations Technik" to analyse them using graph theory (attention: no further active development!)
- ***price***: free for education and research
- ***platform***: Windows
- ***functionalities***: analyses based on graph theory
- ***interaction design***: software is not maintained any longer

Mentimeter (Mentimeter, https://www.mentimeter.com/)
- ***description***: presentation tool with short quizzes, visualizes results
- ***price***: free, basic, pro
- ***platform***: web
- ***functionalities***: questions: multiple choice, image choice, word cloud, open responses, scales, questions from audience, + regular slides and some advanced features
- ***interaction design***: tap / click

MindManager (MindJet, https://www.mindjet.com/)
- ***description***: Mind Mapping Software
- ***price***: 350 € (Enterprise versions also available)
- ***platform***: macOS, Windows
- ***functionalities***: various templates which define certain aspects of the graph (e.g., shapes, types of lines); different views (schedule, priority, etc.)

MindMapper (Sim Tech Systems, http://www.mindmapper.de/)
- ***description***: seems outdated (site is from 2014)
- ***price***: 240€
- ***platform***: Windows, iOS, Android

MindMeister (MeisterLabs, https://www.mindmeister.com)
- ***description***: commercial mind mapping application
- ***price***: 0 € (3 Maps), 5 €/month (personal), 8.50 €/month (Pro, e.g. team support), 12.50 €/month (Business)
- ***platform***: web-based
- ***functionalities***: typical mind mapping functinalities
- ***interaction design***: inline menus to change nodes, links etc., simple option to create outlines of a group (just select a style and all sub-nodes will be visually grouped together), very interesting view of changes (like a time line, dots mark changes, user can choose to auto-play changes)

MindNode (Ideas on Canvas, https://mindnode.com)
- ***description***: mind mapping application with great visuals and basic functionality
- ***price***: 30 $
- ***platform***: macOS, iOS
- ***functionalities***: library of icons included, allows creation of to-do lists; outline view
- ***interaction design***: a single sidebar with a couple of options, but mostly interaction is done on the nodes themselves; pressing special keys changes the behavior (e.g., make cross connections between nodes)

Mindomo (Mindomo, https://www.mindomo.com/de/)
- ***description***: mind mapping and concept mapping application on the web
- ***price***: free (3 maps), various packages (e.g., 6 €/month)
- ***platform***: macOS, Linux, Windows, iOS, Android, web-based (but with native clients)

- ***functionalities***: saves all changes as revisions; allows to take notes as audio or video; presentation mode; templates; export options; task manager functionalities
- ***interaction design***: branches can be hidden (using + and - buttons on the branch), menu in the corner of each node (inline), drag & drop automatically creates new connections (e.g. while moving a node to another branch), bezier handle on links (to change the angle of the arrow), "enter" on a node creates new sub-branch, CMD-drag to create arrow, auto layout of branches, presets (colors, shapes…), extra area to take notes, images and videos can be added to nodes (including a library of symbols, smileys etc.), presenter functionality to share a selected area of the screen

OmniGraffle (Omni, https://www.omnigroup.com/omnigraffle/)
- ***description***: vector-based graphics tool with focus on outlines
- can also be used to create concept maps (though this is not the focus)
- ***price***: 99 $, 199 $
- ***platform***: macOS, iOS
- ***functionalities***: 2 Versions: Standard & Pro (extended features, especially with regard to export and working with layers, aimed at professional graphic designers); lots of drawing features (e.g., control of shapes, text flow, alignment)
- ***interaction design***: relies on various options menus and sidebars focussing on individual aspects of selected elements

Popplet (Notion, https://popplet.com/)
- ***description***: web-based mind mapping tool, focussed on collaboration
- ***price***: 5€
- ***platform***: iOS, web
- ***functionalities***: mentions the name of the collaborator at each bubble (nice idea)

Rationale (Critical Thinking Skills, https://www.rationaleonline.com)
- ***description***: argument mapping tool (see van Gelder 2007)
- ***price***: free test version, 49 $+ (year)
- ***platform***: web
- ***functionalities***: quick start feature for onboarding (example templates of argument maps, with notes that show how they work); overview pane (semi-transparent, shows which part of the overall map is currently visible in the main window)
- ***interaction design***: point & click

Scapple (Literature & Latte, http://www.literatureandlatte.com/scapple/overview)
- ***description***: focussed on using concepts as a tool for writers (in conjunction with writing software Scrivener)
- ***price***: 15 $
- ***platform***: macOS, Windows
- ***functionalities***: exports in various formats (images, PDF); supports images in nodes; free arrangement of concepts
- ***interaction design***: extensive use of drag & drop = click creates node, dragging node on another creates connection, holding certain keys while doing so changes the direction of connections; however, you need to know what to select and where to drag in order to be able to use the software

Sero! (Sero! Learning Assessments Inc., https://serolearn.com/)
- ***description***: focuses on assessment with concept maps, e.g., drag & drop answers
- ***price***: several tiers
- ***platform***: web-based
- ***functionalities***: assessment platform with concept maps
- ***interaction design***: button-based, e.g., with icons on top

Smart Draw (SmartDraw Software, https://www.smartdraw.com/)
- ***description***: flexible graphics tool
- ***price***: 10 $ (month)
- ***platform***: web-based
- ***functionalities***: a variety of templates for diverse types of graphics (including mind maps)

- ***interaction design***: a lot of interesting interactions: keyboard navigation, add parts by mere clicking, auto-alignment of parts; combines assessment options (e.g., click, then fill multiple-choice item)

Spicy Nodes (Spicy Nodes, http://www.spicynodes.org/)
- ***description***: API allowing to browse large amounts of data (= creates nodemaps), last update in 2013
- ***price***: unknown
- ***platform***: web-based

The Brain (TheBrain Technologies, http://thebrain.com/)
- ***description***: note taking & file management using a mind map like link structure
- ***price***: base version free, Pro version 219 $
- ***platform***: macOS, Windows, iOS, Android
- ***interaction design***: active nodes are made bigger and moved to center, everything surrounds the active node

Think Map (Thinkmap, http://thinkmap.com/)
- ***description***: visualization technology for complex data
- ***price***: no information provided without contacting sales
- ***platform***: web-based
- ***functionalities***: 4 types of visualizations: cluster, spider, hierarchy, chronology
- ***interaction design***: concepts float around (and can be dragged), filters on the right allow to focus on specific aspects, mouse overlay with additional information

TM4L (not maintained, https://sourceforge.net/projects/tm4l-plugins/)
- ***description***: uses topic maps in an e-learning environment, inactive

VisiMap (CoCo Systems, https://www.coco.co.uk/index.html)
- ***description***: basic mind mapping application
- ***price***: 34.50 pound
- ***platform***: Windows

Visio (Microsoft, https://products.office.com/en-us/visio/flowchart-software?tab=tabs-1)
- ***description***: diagram software with various templates
- ***price***: 300 $ (or monthly subscription)
- ***platform***: Windows

Visual Concept (unknown, http://visual-concept.co.uk/)
Server inaccessible, seems offline

Visual Mind (Buzan Organization, http://visual-mind.com/)
- ***description***: mind mapping application
- ***price***: 109$ +
- ***platform***: Windows

VUE (Tufts University, http://vue.tufts.edu/)
- ***description***: visual tool to manage resources for learning and research
- ***price***: free
- ***platform***: macOS, Windows, Linux
- ***functionalities***: extends concept mapping approach to digital content, people can link content to concept nodes, meta data for nodes (notes, keywords, categories, ontological relations), can merge two maps, can calculate a connectivity matrix, exploration tools (can change the opacity or zoom level of selected group), layer functionality (like Photoshop)
- ***interaction design***: automatically creates groups for nodes with connections (can be moved in 1 click), has a special tool which automatically creates nodes when you drag an arrow to an empty space, alignment functionality (though only in a menu), many style functionalities (shapes, colors…) in a concise toolbar

Xmind (XMind, http://www.xmind.net/de/)

- ***description***: mind mapping application
- ***price***: 89 € (Pro)
- ***platform***: macOS, iOS, Windows
- ***functionalities***: Gantt view of projects, add notes to concepts, group concepts (using shapes), icons can be added to concepts in order to show additional meaning (e.g., importance), icon library, templates for structures (e.g., mindmap style, concept map style)
- ***interaction design***: nice onboarding, shows placeholders when dragging nodes next to others (to create new connections), bezier-style handles to change angles of arrows, nice toolbar to change design (including type of connection)

Appendix C: UX problems and opportunities identified in the study in Chapter 7

Table 26: *Results (in terms of UX problems and opportunities) in Chapter 7*

Result	Prototype		
	a-1 (computers), N = 13)	a-1 (tablets), N = 11	a-2 (tablets), N = 11
role of selector icon (severity: 3)	unclear: 4 automatic switch between "select" & "1x" caused confusion: 3	unclear: 5 automatic switch between "select" & "1x drawing mode" caused confusion: 4 clear: 2	unclear: 4 clear, but hover effect unclear: 1 clear, but considered unnecessary: 1
use of 1x vs. infinity functionality (severity: 3)	not found: 7 found, but took time to understand: 1 found: 1 not found & wrong understanding: 1 found, but not used: 1	found, but confused: 4 found: 2 not found: 3	not found: 2 found, but confused: 3 not found, but right understanding: 1 found: 2
Problems manipulating the direction of arrows (severity: 3)	8	6	6
scroll mode (severity: 3)		causes problems when user forgot to deactivate: 5 not understood: 1 clear, but cumbersome: 1	causes problems when user forgot to deactivate: 2 found, but negative view: 1 not found: 1 touchscreen functionality too limited: 1
Zoom feature (severity: 3)	not found: 6 found: 1 found late: 1	found: 1 found late: 1 not found: 4 found, but should be without steps: 1	not found: 5 found late: 3 found, but negative: 1

save icon can be confusing (severity: 3)	6	2	3
understanding how to draw arrows took time, not intuitive (severity: 3)	had troubles, but found solution: 7 failed to find solution: 1	had troubles, but found solution: 5 found, no troubles: 1	had troubles, but found solution: 6
"snap to grid" unclear (severity: 3)	6	3	2
judgment of 1x vs. infinity functionality (severity: 2)	(+) 2	(+) 2	(+) 2 (–) 1
adding labels to links not intuitive (severity: 2)	used concepts for link labels: 2 confused because labels had to be explicitly activated after link creation: 1 found, but only after some time: 1	used concepts for link labels: 2	used concepts for link labels: 2
Freehand drawing tool (severity: 2)			(–) 1 (+/–, e.g. good but not necessary) 7
Missing: select all (severity: 2)		3	1
leaving writing field can cause troubles (severity: 2)		3	
provide more "design" options (e.g., colors) (severity: 2)	yes: 2 no: 1	no: 1	yes: 3 maybe: 1
provide an onboarding (severity: 2)	2	1	
add "copy & paste" feature (severity: 2)	5	2	
buttons lack labels (severity: 1)	2		
grid icon not understood (severity: 1)	2	1	
set font options (severity: 1)	yes: 1	yes: 1	not necessary: 1
provide export function (severity: 1)			2

canvas size (severity: 1)	too limited: 2 unclear about size: 1	too limited: 2	
use of right click (severity: 1)	tried to delete object: 1 tried to save: 2		
provide multimodality, e.g. insert images (severity: 1)	1		
drawing toolbar should be repositioned (severity: 1)	1		
design should be more interactive, friendly, fun to use (severity: 1)	yes: 1 no, nice: 3	yes: 2 no, nice: 1	no, nice: 2
provide possibilities to work with layers (severity: 1)			1
provide warning when exiting a map without saving (severity: 1)		1	
BUG when loading a document (severity: 1)		1	
not clear how to create shapes (severity: 1)			1
create option to provide a title of a map (severity: 1)	1		
provide sharing & collaborative functions (severity: 1)	1		

Appendix D: UX problems and opportunities identified in the study in Chapter 8 (RQ 1)

Table 27*: Results (in terms of UX problems and opportunities) in Chapter 8*

Result	Number of participants (N= 31)	Severity
gesture navigation missing	11	3
auto-drawing of arrows confusing, should be adaptable	10	3

scroll tool unclear	unclear: 5 used toolbar hiding as "alternative": 2 understood, but cumbersome: 1 took some time, but then understood: 1	3
shape recognition needed for freehand	suggested shape recognition: 4 not used freehand because it is ugly: 4	3
more shapes & design functions needed	7	3
double tapping of element should activate it; selector mode unclear	6	3
trouble finding how to write into shapes and on lines	not found: 2 difficulties finding, but finally found it: 4	3
applying custom colors unclear (tap to activate)	5	3
freehand should allow for drawing little things, not only shapes	4	2
menu labels missing	3	2
delete function not found	3	2
dividing arrows missing	3	2
freehand should also be used for links (too limited because it fills shapes)	3	2
bidirectional links missing	3	2
note taking feature missing	3	2
select all elements in an area missing	3	2
copy & paste missing	3	2
non-directional links missing	2	1
more fonts needed	1	1
infinite grid needed	1	1
grouping elements missing	1	1
adding symbols and emojis should be possible	1	1
auto-adapt font size to shape size	1	1
design not nice	1	1

Appendix E: Definitions for Coding of Critical Incidents in the study in Chapter 8

***Table 28**: Definitions used to code critical incidents*

Code for critical incident	Definition
difficulties with autoflow	behavior of P indicates that they dislike the autoflow of links, for example by trying to "drag" links somewhere else, shaking heads after link appears, deleting and redoing links, moving elements around or adapting options to change the autoflow
problem closing the onscreen keyboard	P demonstrates difficulties of closing the onscreen keyboard (e.g., tapping outside of keyboard multiple times)
double tap for interface zoom causes troubles	P double taps the interface, zoom happens --> P finally manages to exit the mode
use of multitouch gestures	P uses multitouch gestures to zoom or scroll
confusion with scroll mode	P has scroll mode active, behavior shows difficulties exiting it (e.g., activating other elements)
tapping elements without selection mode	P taps elements without selection mode activated
creation of elements due to touching UI elements nearby	P creates an element that is unwanted, e.g. because P missed a user interface target or performed a gesture
difficulties writing in concepts	P shows behavior that indicates difficulties of adding labels (e.g., writing by hand, writing into hex color field…)
difficulties writing on links	P has difficulties to write on links (e.g., does not find edit button on links and tries to write by hand, uses regular shapes for links, or writes into custom color field)
deleting of elements	P has difficulties deleting elements, for example by crossing elements out
selecting all or multiple elements missing	P shows behavior that would benefit from a "select all" or "select multiple" function, for example visible if users moved several elements in a row
exit to home screen	P taps on "home button", concept map is closed
left panel closed = problems finding options	visible problems because of closed left panel
linking elements causes troubles	P wants to create a link but does not succeed, e.g. by dragging to empty area or tapping elements instead of dragging between them
difficulties applying custom colors	P tries to apply custom colors, but does not succeed in doing so (e.g., by selecting a custom color, but not applying it)
difficulties adapting shapes and lines	behavior of P indicates difficulties adapting shapes and lines

difficulties applying typography options	P has difficulties applying typography options
difficulties editing design options	P has difficulties editing design options of concepts or links
freehand used for shapes but undone, does not look nice	P uses freehand shapes, but undoes them
freehand should be usable for lines	P creates lines and annotations with freehand tool
handwriting used with freehand	P uses freehand drawing to write by hand
difficulties because freehand lines do not move with elements	difficulties observable because freehand elements do not move with other elements (e.g., handwritten text with elements)
use of freehand shapes (without discarding them)	P uses freehand to create shapes, keeps them
bugs	P experiences a bug (unintended behavior of the application)

Appendix F: Momentary User Experience Results in the study in Chapter 8

Table 29: *Results on momentary user experience in Chapter 8*

UX findings	Instances	Participants
selecting elements	177	30
– participants have difficulties selecting elements → participants were able to solve them	100	28
– participants have difficulties selecting elements → participants were not able to solve them (e.g., undoing of element creation)	59	17
– participants have difficulties because multiple elements overlap in layers	9	6
– participants suggest that it should be possible to select multiple or all elements on touchscreens	8	7
– participants have difficulties selecting text	1	1
creating content	167	23
(a) labels on concepts	111	15
– participants have difficulties creating concept labels → solved	14	9
– participants have difficulties creating concept labels → solved	7	5
– participants have difficulties creating concept labels → workaround with freehand writing	87	7

– participants have difficulties creating concept labels because the left panel is closed → solved	3	2
(b) labels on links	39	10
– participants have difficulties creating link labels → solved	3	3
– participants have difficulties creating link labels → aborted	2	2
– participants have difficulties creating link labels → workaround with regular shapes	15	3
– participants have difficulties creating link labels → workaround with freehand writing	17	4
– participants have difficulties with copy & paste on link labels (does not update the text in the label)	2	1
(c) on-screen keyboard use	17	7
– difficulties closing the on-screen keyboard → solution found	14	6
– difficulties typing with on-screen keyboard	3	2
interacting with the canvas	134	26
– use of multitouch gestures	74	22
– "double tap to zoom" causes difficulties	32	14
– "scroll mode" causes difficulties → participants find solution	18	15
– "scroll mode" causes difficulties → solution not found	5	3
– participants express need for limitless canvas	3	2
– participants have difficulties zooming → solution found	2	2
autoflow of links causes problems	72	28
– → participants reposition elements	23	14
– → participants delete & recreate elements with alternative design options for links	21	11
– → participants delete links without recreating them	12	8
– → participants finally accept the provided autoflow	6	6
– → participants change content (e.g., use passive)	4	3
– → participants use workaround with freehand drawing	4	3
– → participants change the size of elements to adapt flow	2	2
creating links	71	20
– participants have difficulties creating links → solution found	31	19
– participants have difficulties creating links → freehand drawing as workaround	31	5
– participants have difficulties creating links → abort operation	9	7

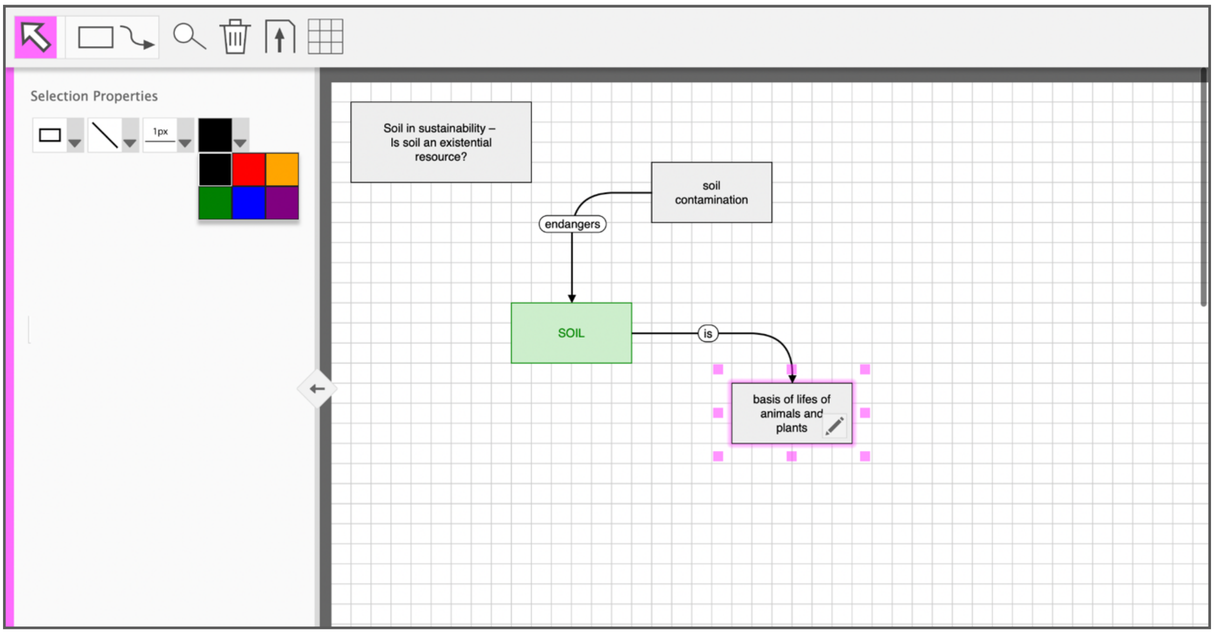
editing design options of elements	42	16
– difficulties applying custom colors	19	11
– difficulties applying typography options	8	4
– difficulties applying design options → solution found	15	7
use of freehand drawing tool	27	15
– freehand drawing used for annotations or shapes	10	4
– freehand drawing tried for annotations or shapes → participants undo or delete their drawings	10	8
– participants emphasize that freehand drawings should be more flexible (e.g., allow creating links or handwriting)	4	3
– participants have difficulties because freehand elements do not move with related elements (e.g., handwritten text in concepts)	2	1
– participants emphasize that freehand elements should look nicer	1	1
deleting elements	20	11
– → solved by selecting and deleting of elements	7	5
– → solved by undoing	11	7
– → solved by crossing out with freehand drawing tool	1	1
– → not solved	1	1
other issues		
– accidental creation of elements (e.g., due to tapping the canvas instead of user interface elements)	19	7
– bugs	8	8
– accidentally exiting to home screen	8	6
– infinity functionality unclear	5	1
– difficulties aligning elements because of grid function	5	4
– participants express that a type of link is missing	3	3

Appendix G: Description of Prototypes of Chapter 11

Tool 1 (see Fig. 73) is based on design suggestions for digital concept mapping tools from a project focused on optimizing for pragmatic UX in digital concept mapping, particularly with respect to usability (Weinerth, 2015). The suggestions were derived following a user-centered design process in three iterations with 90 user tests. Tool 1 implements the derived suggestions. In particular, it has the following features:

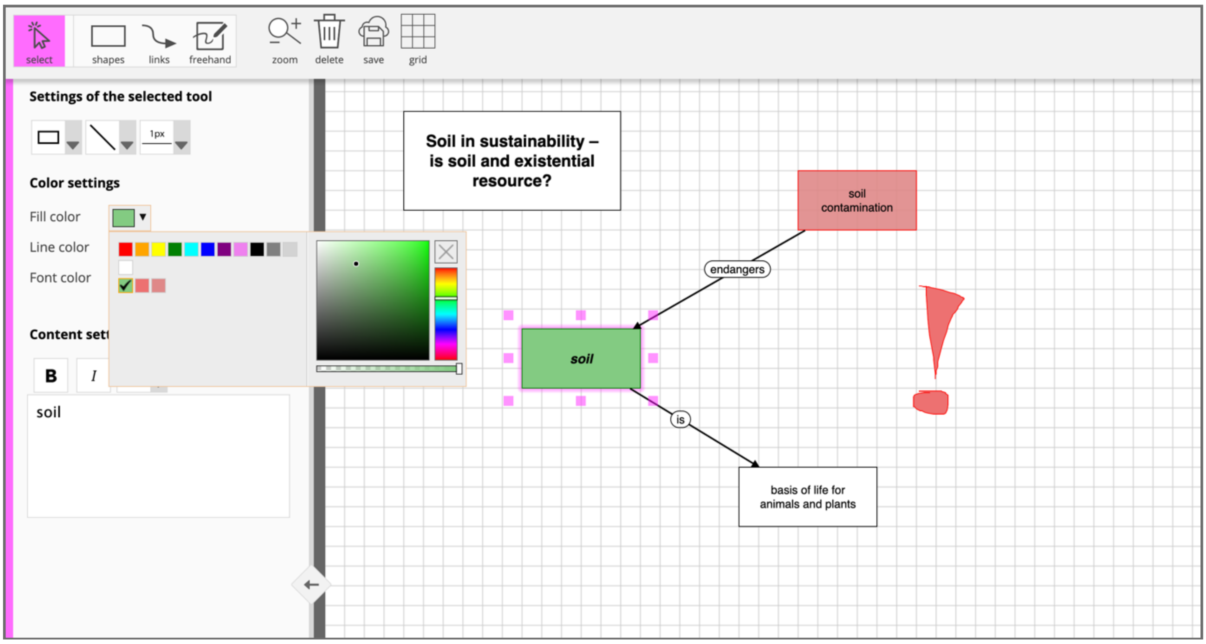
- basic shapes (four shapes, with dedicated modes for creating one or unlimited objects),
- links that automatically connect to objects (and update when the objects are moved),
- limited options for styling elements (six colors, six line types, four line thicknesses)
- dedicated zoom and scroll modes on tablets (when activated, touching the screen adapts the canvas display rather than creating new elements).

***Fig. 73**: Tool 1 focused on optimizing for usability*



Tool 2 (see Fig. 74) was developed in a project focused on optimizing for holistic UX, and thus including both the pragmatic and hedonic dimensions. It was based on user research (with a total of 88 participants) and two iterations of user tests (with a total of 66 participants). Two main changes were instituted compared to Tool 1. First, Tool 2 addressed a series of usability issues discovered in the tests, specifically by removing the option to switch between modes for creating single or unlimited objects, enhancing the menu icons by including labels, and providing onboarding instructions at the beginning that explain the most important tools. Second, Tool 2 includes a set of hedonic options frequently desired by users, specifically enhanced styling options and a basic freehand drawing tool for adding manual annotations (like exclamation marks).

***Fig. 74**: Tool 2 with stronger focus on holistic user experience*



Appendix H: Rubric Used to Assess Concept Maps in Chapter 11

Table 30: *Scoring rubric for evaluating the concept maps based on Besterfield-Sacre et al. (2004)*

Quality criterion	0	1	2	3
Comprehensiveness	The map does not define the topic or is completely off-topic. The knowledge is not visible or not related to the topic.	The map lacks an adequate definition of its subject (for example, no central concept visible or central concept too general). The knowledge is very simple and limited. Low breadth of concepts (for example, relevant aspects are only minimally covered, no or limited mentioning of important sustainability categories). The map barely covers the topic.	The map defines the topic adequately (for example by defining a relevant central concept or a focus question). However, the knowledge is limited in some areas (for example, some key areas of sustainability and relevant aspects are covered but others are missing). The map demonstrates a limited understanding of the topic (for example because relations and dependencies within the area of sustainability are only covered to a limited extent).	The map completely defines the topic. Regarding content, only a few aspects of sustainability are missing (for example, all relevant categories of sustainability and numerous content areas are covered, like ecological, economic, and social factors).
Organization	The concepts in the map are not at all or mostly not connected. There are no visible branches or other structures in the concept map.	The concepts in the map are only linearly connected. There are only a few or no connections between branches of the map. Concepts are not well integrated.	The map has an adequate organization within some branches. Some signs of integrating different areas are visible, but not completely. Some feedback loops or other dependencies are depicted.	The map is well organized and captures several feedback loops or other dependencies. The structure is highly developed and well connected.
Correctness	The correctness of the map cannot be evaluated. Numerous concepts are unlabeled or not readable.	The map is simplistic and contains numerous misconceptions about the topic. Inappropriate terms are used.	The map has some misconceptions about the topic. However, most relations are correct. There are some smaller	The map integrates the concepts very well and demonstrates a thorough understanding of the topic. There are few or no

		The map reflects an inaccurate understanding of the topic.	errors and incorrect relations concerning the field of sustainability.	misconceptions or other errors. The central relations within the field of sustainability are covered.

Appendix I: Analysis of qualitative feedback regarding the prototypes' UX in Chapter 11

In addition to the quantitative UX measurements obtained via the UEQ, we asked participants to provide feedback about the UX in freeform texts. This freeform text feedback provides insights into the reasons behind the participants' reported user experience. Positive comments focused mostly on ease of use (3 mentions) or a generally pleasurable experience (10 mentions). Negative comments often focused on specific functionalities that participants experienced as annoying. On tablets, for example, the dedicated modes for selecting objects vs. zooming or scrolling were perceived as confusing (e.g., 14KM: "when the scroll button is active I couldn't select any item. […] It is not practical to press a button each time I want to scroll"). Thus, numerous suggestions referred to better scaling and scrolling options, in particular using finger motions (e.g., 5LY, 14KM, 14TQ) or automatically selecting an object when it is tapped (regardless of which mode is active). These results indicate that the concept mapping prototypes might need to be more thoroughly adapted to multi-touch devices. The current solution with menus and dedicated modes might be acceptable on computers, but not on tablets, where more direct and enjoyable interactions might be more appropriate (Hwang et al., 2012). Thus, tablet interfaces are not more user-friendly per se, but must be specifically adapted to the interaction style inherent to this device.

Interestingly, although the differences on the UEQ between prototypes were insignificant, the participants' feedback on the earlier tool nevertheless frequently reflected aspects that were addressed in the later tool, in particular providing onboarding instructions (e.g., 1SR: "the presentation of the tool was good"), making it possible to customize colors and fonts, or removing the ability to switch between modes for creating single or unlimited objects. One of the most frequent suggestions on tablets was an alternative interaction style involving drawing a concept map with a stylus (e.g., 25LD: "draw more with a pencil on the tablet, and then the application would render the shapes more attractive so that I would not have to select different tools without end, as this is annoying and takes time"). This feedback suggests that the current free-hand drawing tool focused on adding simple annotations is too limited.

Appendix J: Checks of Bias and Assumptions in the Linear Regression Models of the study in Chapter 11

For each of the linear regression models, we checked for evidence of bias in the model as suggested by Field (2018). First, we checked case-wise diagnostics for standardized residuals. Field (2018) suggests that in a normally distributed sample, 95% of cases should be within two standard deviations. In our sample, we would expect this to be true for 26-27 cases in the computer group (N = 28) and 40-41 cases in the tablet group (N = 43). Table 31 shows how many cases in each model fell within this expected range. The model predicting pragmatic UX from fulfillment of pleasure and stimulation on tablets is the only model outside of the expected range, with four cases more than -2 standard deviations from the expected value. However, two of these cases were very close to -2 standard deviations, with z-scores of -2.026 and -2.043, respectively. Thus, we do not consider these values as indications of major bias in the model.

Table 31*: Casewise diagnostics*

Linear model	Cases inside the expected range
Global need → pragmatic UX	Computers: 28, Tablets: 41
Global need → hedonic UX	Computers: 27, Tablets: 42
Autonomy → pragmatic UX	Computers: 27, Tablets: 40
Autonomy → hedonic UX	Computers: 27, Tablets: 41
Competence → pragmatic UX	Computers: 27, Tablets: 42
Competence → hedonic UX	Computers: 27, Tablets: 42
Relatedness → pragmatic UX	Computers: 28, Tablets: 41
Relatedness → hedonic UX	Computers: 28, Tablets: 42
Pleasure → pragmatic UX	Computers: 27, Tablets: 39
Pleasure → hedonic UX	Computers: 27, Tablets: 42
Security → pragmatic UX	Computers: 27, Tablets: 42
Security → hedonic UX	Computers: 28, Tablets: 42
Influence → pragmatic UX	Computers: 28, Tablets: 41
Influence → hedonic UX	Computers: 27, Tablets: 41
Self-actualizing → pragmatic UX	Computers: 27, Tablets: 40
Self-actualizing → hedonic UX	Computers: 27, Tablets: 42
Attractiveness → intention to use	Computers: 27, Tablets: 40
Attractiveness → comprehensiveness score	Computers: 26, Tablets: 42
Attractiveness → organization score	Computers: 27, Tablets: 41
Attractiveness → correctness score	Computers: 27, Tablets: 41
Attractiveness → total score	Computers: 26, Tablets: 41

Second, we checked for signs of heteroscedasticity and a non-normal distribution of residuals (Field, 2018). For heteroscedasticity, we checked scatterplots of standardized predicted values against standardized residuals for each of our models (ZResid vs. ZPred). Heteroscedasticity would be reflected in graphs with a funnel-like pattern in which values become more spread out. Most of our models exhibited a random distribution of values, indicating that the homoscedasticity assumption is met (see Fig. 75 for an example). The graph for the model with need for influence and popularity predicting the pragmatic dimension of UX shows a clear funnel-like pattern indicative of heteroscedasticity (see Fig. 76). However, we already suggest treating the results for social needs with caution in the present study (see discussion section) as the task did not involve social interaction. The graph for the model with need for security and control predicting the hedonic dimension of UX exhibited a similar pattern (see Fig. 77), suggesting that this model should also be interpreted with caution.

Fig. 75*: ZResid vs. ZPred for the model with fulfillment of need for pleasure and stimulation predicting the hedonic quality of UX*

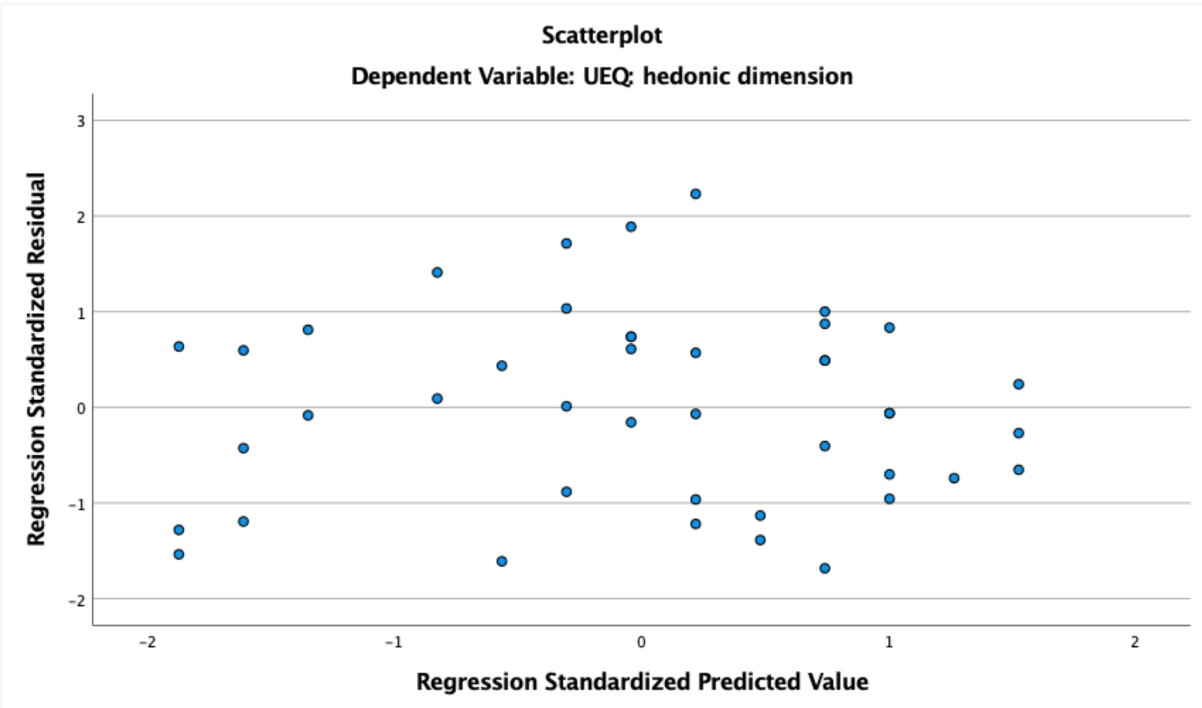


Fig. 76*: ZResid vs. ZPred for the model with fulfillment of the need for influence and popularity predicting the pragmatic quality of UX*

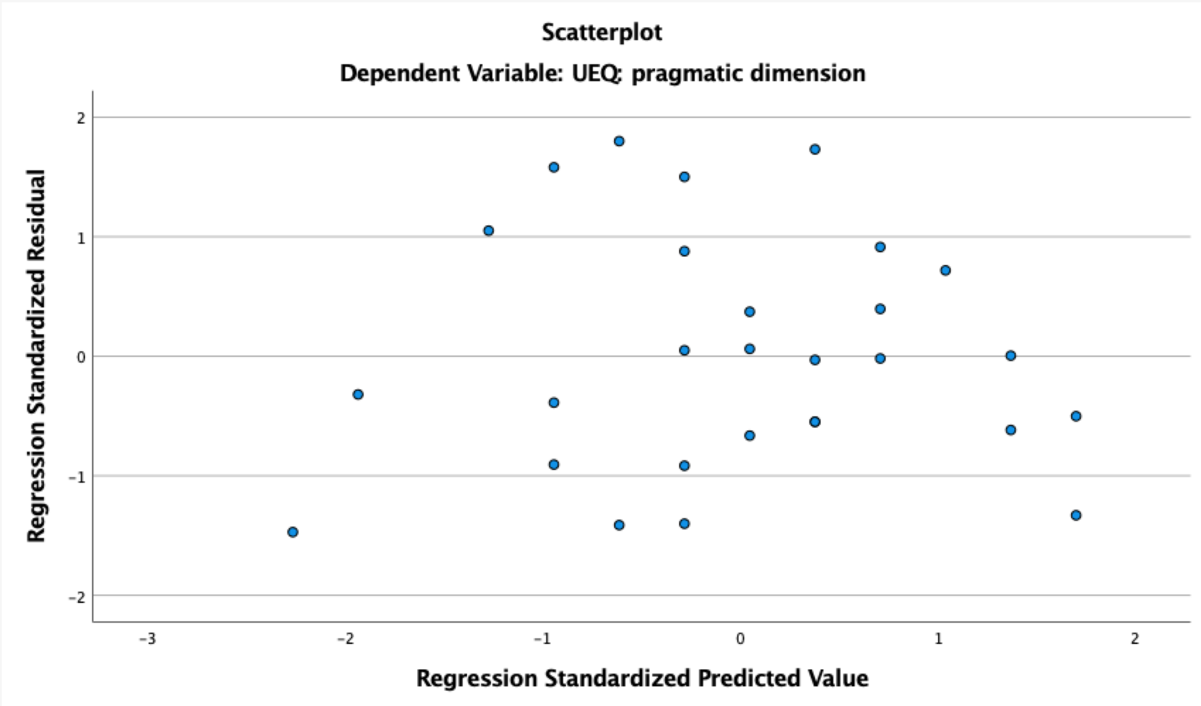
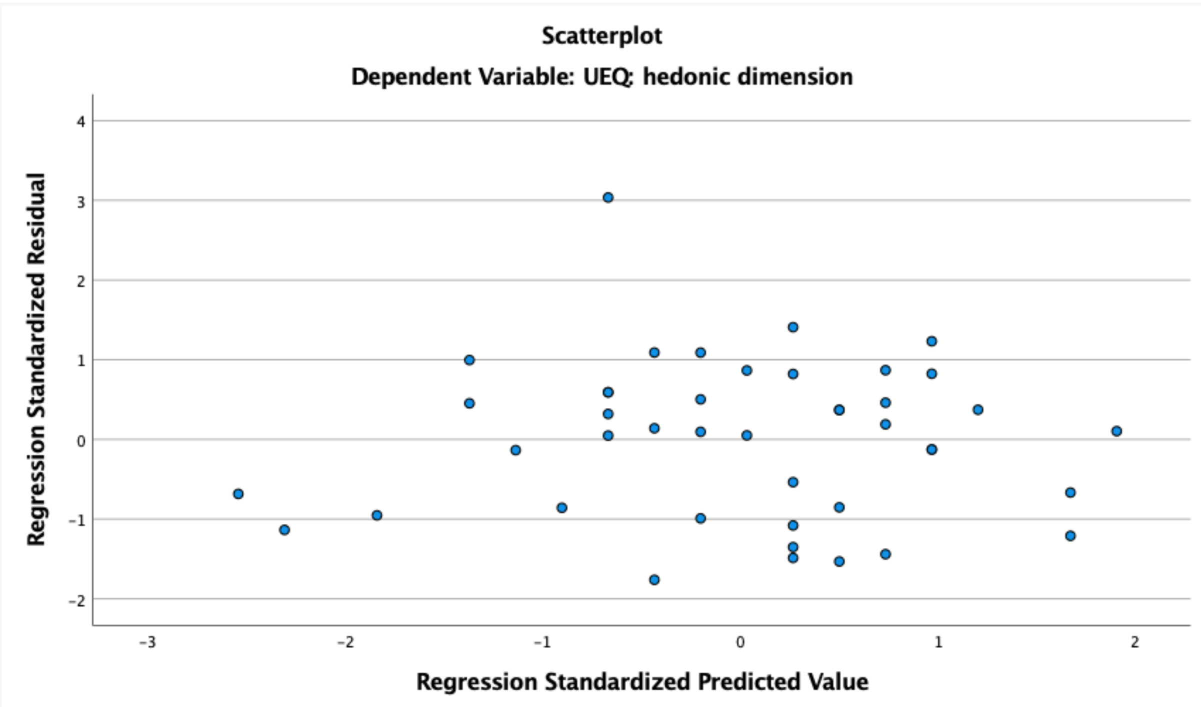


Fig. *77: ZResid vs. ZPred of the model with fulfillment of the need for security and control predicting the hedonic quality of UX*



To test for non-normal distributions of residuals, we checked histograms and normal probability plots (P-P plots) (Field, 2018). A minority of histograms and P-P plots suggested some concerns regarding the normality of residuals, particularly in the computer group (models: attractiveness → organization score, pragmatic dimension of UX → security). Consequently, we performed bootstrapping in order to obtain robust confidence intervals and significance tests (Field, 2018).

Appendix K: Criteria and Levels From Workshop 1 in Chapter 12

***Table 32**: Criteria and levels discussed in Workshop 1*

modes	functions or purposes			
	decorative or engaging	attention-driven	content-driven	explicit
Color = use of color as a design feature in concept maps	Color is used to make the concept map look nice or attractive.	Color is used to guide viewers' attention, e.g. by marking more important elements.	Color is used to distinguish between different categories of content meaningfully.	The concept map explicitly explains the meaning of color use, e.g. with a legend or annotations.
Shapes = use of different shapes for concepts (e.g. rectangles, circles, clouds) or links (e.g. different arrowheads, different line types)	Shapes are used to make the concept map look nice or to provide more variety.	Shapes are used to guide viewers' attention, e.g. by marking important elements.	Shapes are used to communicate content, e.g. by distinguishing between different categories of content.	The concept map explicitly explains its use of shapes, e.g. with a legend or annotations.
Size = use of different sizes of elements (concepts or labels)	Sizes of elements are used to make the concept map look nice.	Sizes of elements are used to guide viewers' attention, e.g. by making more important elements bigger.	Sizes are used to communicate content, e.g. by distinguishing between different categories of content (e.g., make examples smaller than other concepts).	The concept map explicitly explains its use of sizes, e.g. with a legend or annotations.
Icons = use of iconic images (emojis, pictograms…) in concept maps	Icons are used to make the concept map look nice.	Icons are used to guide viewers' attention, e.g. by marking important elements (e.g. with an exclamation mark).	Icons are used to communicate or enhance content, e.g. by adding icons to different categories of content.	The concept map explicitly explains its use of icons, e.g. with a legend or annotations.
Images = use of photographs, illustrations, diagrams, or other images in concept maps	Images are used to make concept maps look nice.	Images are used to guide viewers' attention, e.g. by marking important elements.	Images meaningfully communicate or enhance content.	?

Typography = use of typographic features in concept maps, font styles (e.g. bold), font sizes, font variants (e.g. italics)	Typographic features are used to make concept maps look nice.	Typographic features are used to guide viewers' attention, e.g. by marking important elements.	Typography is used to communicate content, e.g. by using different styles for different kinds of elements.	The concept map explicitly explains its use of typographic features, e.g. with a legend or annotations.
Layering of information = nesting of concept maps (submaps inside maps), hyperlinking between maps and additional elements	?	The layered information is used to guide viewers' attention, e.g. by hiding less important parts of the concept map until opened on purpose.	The layered information meaningfully enhances the element of the concept map, e.g. by providing links to additional relevant material on the web.	The concept map makes explicit how the layered information relates to the concept (e.g. "see link for definition").
Spatial arrangement of elements = framing and positioning of elements on the canvas	Elements are arranged for creating a nice look.	Elements are arranged in a way that guides viewers' attention, e.g. by putting the most important elements above.	Elements are arranged in a way that communicates or enhances content, e.g. by putting related elements closer to each other.	The concept map explicitly explains spatial arrangement, e.g. by dividing the map into different, explicitly labeled sections.
Temporal dynamics = animation and transitions in concept maps (either between different states of a map or between different concepts)	Animation is used as a decorative effect.	Animation is used to focus attention on the content that is relevant at a particular time.	Animation meaningfully explains content, e.g. temporal succession of events or development of the topic over time.	?

Appendix L: Scoring Rubric Draft from Workshop 2 in Chapter 12

***Table 33**: Draft of scoring rubric in Workshop 2*

	0	1	2	3	4	5	6
aesthetics use design to create a nice, pleasing look that helps engaging with the concept map	does not apply to the concept map and the topic	The design does not show any attempts to make it pleasing.	The design shows limited attempts to make it pleasing, but only uses a very limited range of design means. Furthermore, these seem random.	The design shows limited attempts to make it pleasing, but uses different design means to do so. However, these seem random.	The design shows considerable attempts to make it pleasing and explores a range of design means to do so. Their use is guided by principles, but these are not applied consistently enough.	The design is pleasing overall and uses a range of design means. They are largely applied consistently. Aesthetic principles are employed. However, a few inconsistencies or areas for improvement exist.	The design is pleasing and makes the concept map a pleasure to read. A range of design means is applied consistently. Aesthetic principles are adequately employed.
attention use design to guide focus, e.g. to most important aspects	does not apply to the concept map and the topic	The design does not show any attempt to help the reader focus on relevant aspects.	The design shows only limited attempts to help the reader focus on particular aspects but these seem random.	The design shows limited attempts to help the reader focus on particular elements. These seem to be applied with some consistency but they create a tension (e.g. because they are distracting).	The design shows considerable attempts to help the reader focus on particular elements. These are mostly applied consistently, but they create a tension (e.g. because they are distracting).	The design shows considerable attempts to help the reader focus on particular elements. These are applied consistently and appropriately, but some areas for improvement still exist (e.g., some minor distractions	The design meaningfully helps the reader to focus on the relevant aspects. The design uses an adequate amount of elements to help the reader focus and applies them consistently and appropriately.

						still exist, or a few elements would profit from emphasis).	
content use design to distinguish content, e.g. by categorizing it	does not apply to the concept map and the topic	The design does not include any element that meaningfully adds relevant criteria to the content.	The design shows limited attempts to add relevant criteria to the content, but these seem random and do not serve the overall purpose of the concept map.	The design shows attempts to add relevant criteria to the content. There is an overall pattern, but it does not serve the overall purpose of the concept map.	The design shows considerable attempts to add relevant criteria. However, these are not explicit enough (e.g., there is no legend), making it a bit hard to interpret the concept map.	The design adds relevant criteria to the content and makes the use of these criteria explicit (e.g. with a legend). However, the understanding could be enhanced (e.g. by sticking to established associations, e.g. red for negative).	The design excels in meaningfully adding relevant criteria to the content. The use of these criteria is explicit (e.g. with a legend) and makes understanding easy (e.g. by sticking to established associations, e.g. red for negative).
dynamics use design to highlight relevant changes in the described content, e.g. by highlighting feedback loops	does not apply to the concept map and the topic	The design does not include any element that enhances the dynamic aspects of the topic.	The design includes some elements that point to dynamic aspects of the topic, but these are wrong or not meaningful for the overall topic.	The design includes some elements that point to dynamic aspects of the topic. These are meaningful, but they are not applied consistently.	The design includes a broad range of elements that point to dynamic aspects in the topic. These are meaningful and applied consistently, but there are many areas missing (e.g. they only consider increasing dynamics, but decreasing dynamics would also be important).	The design includes a broad range of elements that point to dynamic aspects of the topic. These are meaningful, applied consistently, and cover most areas that are relevant.	The design excels in demonstrating relevant dynamics involved of the topic. These appropriate design elements are meaningful, applied consistently, and cover all areas that are relevant.

illustration use design to provide meaningful additions to concept map, e.g. by including images of concepts	does not apply to the concept map and the topic	The design does not include any illustrations or other meaningful resources that enhance the content.	The design shows limited amounts of illustrating resources. However, these seem random and do not enhance understanding.	The design shows limited amounts of illustrating resources. There is a pattern behind their use, but it is not applied consistently enough (e.g. some illustrations are missing). As such, the resources do not enhance understanding.	The design shows considerable amounts of illustrations and applies them consistently. They somehow add to enhancing understanding but could be substantially enhanced in this regard (e.g., the illustrations are not the best for the purpose they are supposed to serve).	The design includes meaningful resources and applies them consistently. They enhance understanding overall, but some areas of improvement still exist (e.g., by mixing the range of illustrative resources as appropriate for the content).	The design includes meaningful resources and applies them consistently. They fully enhance understanding. The selection of illustrative resources is perfect for the purpose they are serving.

Appendix M: Modular Multimodal Guidelines and Scoring Rubric (developed in Chapter 12)

Section 1: Functions

Beauty and aesthetics: create a pleasing impression

Concept maps can create sensory pleasures by looking at them: They can be beautiful and create a positive impression, regardless of what content they communicate (Moshagen & Thielsch, 2010). Concept maps can also be adapted to your personal tastes. For beauty and aesthetics, please consider:

- create a beautiful look
- carefully balance all multimodal features and the overall layout
- consider the audience of your concept map (what would they like?)
- consider your personal preferences (what do you like?)
- create motivation to look at your concept map

Emphasis and salience: meaningfully distinguish important elements

Concept maps communicate not only content but also the importance of content. By emphasizing elements and carefully creating salience, concept maps create a hierarchy of importance (Kress & Leeuwen, 2021). For emphasis and salience, please consider:

- think about multimodal features that communicate the importance and strength of elements (concepts and links)
- match styling and importance (do the most important elements look the most eye-catching?)
- think about an appropriate reading order (do your elements suggest an ordering that makes sense?)

Categorization: meaningfully distinguish types of content

Topics, processes, and problems often involve different categories of content (in concepts and links). Concept maps can include these categories with multimodal features. By doing so, a concept map can express complexity without looking overly complex. For categorization, please consider:

- think about useful groups of content (concepts and links)
- verify that the groups contribute to the overall topic of the concept map (e.g., do they address the focus question or core topic?)
- think about how to communicate these groups (e.g., should they be physically grouped or grouped by other multimodal means?)

- re-consider the labels for the groups (do they match?)
- close to the end of the concept mapping task, verify the complexity and categorization of your concept map (have you included all relevant groups and added elements accordingly?)

Evolution, sequence, or process: explain how a topic changes or evolves over time

Concept maps can cover elements that dynamically change over time, for example because something evolves, because a certain sequence is involved, or because a certain process happens. Including these elements in concept maps can often create a more appropriate picture of the covered topic. For evolution, sequence, or process, please consider:

- collect evolutions, sequences, or processes that are relevant to the topic of the concept maps, and think about an appropriate way to communicate them in your concept map
- think about who or what causes them, and include this information appropriately in your concept map
- think about the direction of a change (e.g., does it increase or decrease?)
- think about the temporal nature of a change (e.g., does it happen simultaneously or sequential?)
- safeguard to carefully distinguish multimodal features that communicate evolution, sequence, or process from other elements in the concept map

Enriching or adding elements: provide meaningful visual, textual, or auditory elements

Concept maps can include additional content elements beyond the labels of concepts and links, for example images, links, audio files, videos, notes, etc. These additional content elements can communicate information that extends the labels or information that cannot readily be included in the labels. At the same time, any included additional content element needs to serve the overall purpose of the concept map. For enriching or adding elements, please consider:

- verify that additions are relevant and provide value
- define how the additions relate to the labels and put all elements in an appropriate and clear ordering (e.g., does the image illustrate the label or does the label illustrate the image?)
- choose the modal feature that is the most appropriate for any content element (e.g., some information is best presented as an image, others as a video)
- carefully verify that additional content elements serve the overall message of the concept map
- be careful that the elements complement each other, not compete with each other

Validity: communicate how valid the content elements are

Concept maps typically contain propositions (concepts and links), but not all propositions are equally valid (Kress & Leeuwen, 2021). Sometimes, you might have a reason for doubt, or the evidence might be inconclusive. In these cases, multimodal features can help you communicate how sure you are about the validity of a statement. For validity, please consider:

- think about what part of a statement should be altered in terms of validity (the concept or the link?)
- consider how many levels of validity judgments you need
- create a system of multimodal features to communicate your validity judgments, and apply it consistently

Layout and composition: arrange elements in a meaningful way

Concept maps do not only communicate content verbally but arrange it in a certain layout and spatial composition. Such layout and composition helps in clearly communicating the purpose of a concept map. For layout and composition, please consider:

- verify that the overall type of layout corresponds to the topic (Yin et al., 2005; Hay & Kinchin, 2006)
- verify that the spatial arrangement is appropriate (e.g., which elements do you position from left to right, from top to bottom, from center to margin?)
- ensure meaningful use of distances in your concept map

Section 2: General principles

Principle of explicitness and coherence: verify that external viewers can readily understand your concept map, and include information that helps them understand it when appropriate; verify that the relation between all multimodal elements is clear, for example by avoiding that the functions contradict each other; follow established conventions of meaning or explicitly define the meanings of multimodal features

Principle of structured concept mapping: multimodal concept maps serve the purpose of communicating relevant content for a topic; thus, start with creating the content elements, and add multimodal information close to finishing the concept map (when you have a clear picture of what the concept map is communicating)

Principle of meaningfulness of multimodal features: verify that each multimodal feature is used with a purpose, apply the so-called “commutation test” (Kress & Leeuwen, 2021; Barthes, 1967) (change a multimodal feature radically, e.g. into the opposite, to verify whether the meaning is altered; if not, the multimodal feature might not contribute to communicating content meaningfully), refrain from including multimodal features that do not serve any function

Principle of accessibility: verify that all contents are available for all humans, regardless of their respective capabilities (e.g., in terms of color deficiencies); verify that content is understandable when a mode is unavailable (e.g., by using appropriate contrast); verify that multimodal features support each other (e.g., by using a clear structure to help viewers with lower verbal skills)

Section 3: Scoring rubric

Please select the functions that apply to the concept maps first, then distribute the scoring rubric.

Selection	Function	0	1	2	3
☐	**Beauty and aesthetics**: create a pleasing impression	The concept map is not aesthetically pleasing. The use of multimodal features does not achieve this function.	The concept map shows limited efforts to make it aesthetically pleasing. The use of multimodal features does not achieve this function generally, but some indications of achieving it are visible.	The concept map shows considerable efforts to make it aesthetically pleasing. The use of multimodal features generally achieves this function, but some room for improvement is visible.	The concept map is aesthetically pleasing. The use of multimodal features fully achieves this function.
☐	**Emphasis and salience:** meaningfully distinguish important elements	The concept map does not create emphasis and salience. The use of multimodal features does not achieve this function.	The concept map shows limited efforts to create emphasis and salience. The use of multimodal features does not achieve this function generally, but some indications of achieving it are visible.	The concept map shows considerable efforts to create emphasis and salience. The use of multimodal features generally achieves this function, but some room for improvement is visible.	The concept map creates emphasis and salience. The use of multimodal features fully achieves this function.
☐	**Categorization:** meaningfully distinguish types of content	The concept map does not meaningfully categorize types of content. The use of multimodal features does not achieve this function.	The concept map shows limited efforts to categorize types of content meaningfully. The use of multimodal features does not achieve this function generally, but some indications of achieving it are visible.	The concept map shows considerable efforts to distinguish types of content meaningfully. The use of multimodal features generally achieves this function, but some room for improvement is visible.	The concept map meaningfully categorizes types of content. The use of multimodal features fully achieves this function.

☐	**Evolution, sequence, or process:** explain how a topic changes or evolves over time	The concept map does not communicate aspects of evolution, sequence, or process. The use of multimodal features does not achieve this function.	The concept map shows limited efforts to communicate aspects of evolution, sequence, or process. The use of multimodal features does not achieve this function generally, but some indications of achieving it are visible.	The concept map shows considerable efforts to communicate aspects of evolution, sequence, or process. The use of multimodal features generally achieves this function, but some room for improvement is visible.	The concept map communicates aspects of evolution, sequence, or process. The use of multimodal features fully achieves this function.
☐	**Enriching or adding elements:** provide meaningful visual, textual, or auditory elements	The concept map does not add enriching elements. The use of multimodal features does not achieve this function.	The concept map shows limited efforts to add enriching elements. The use of multimodal features does not achieve this function generally, but some indications of achieving it are visible.	The concept map shows considerable efforts to add enriching elements. The use of multimodal features generally achieves this function, but some room for improvement is visible.	The concept map adds enriching elements. The use of multimodal features fully achieves this function.
☐	**Validity:** communicate how valid the content elements are	The concept map does not communicate the validity of content elements. The use of multimodal features does not achieve this function.	The concept map shows limited efforts to communicate the validity of content elements. The use of multimodal features does not achieve this function generally, but some indications of achieving it are visible.	The concept map shows considerable efforts to make it aesthetically pleasing. The use of multimodal features generally achieves this function, but some room for improvement is visible.	The concept map communicates the validity of content elements. The use of multimodal features fully achieves this function.
☐	**Layout and composition:** arrange elements in a meaningful way	The concept map does not have a meaningful layout and composition. The use of multimodal features does not achieve this function.	The concept map shows limited efforts to create a meaningful layout and composition. The use of multimodal features does not achieve this function generally, but some	The concept map shows considerable efforts to create a meaningful layout and composition. The use of multimodal features generally achieves this function, but	The concept map has a meaningful layout and composition. The use of multimodal features fully achieves this function.

			indications of achieving it are visible.	some room for improvement is visible.	